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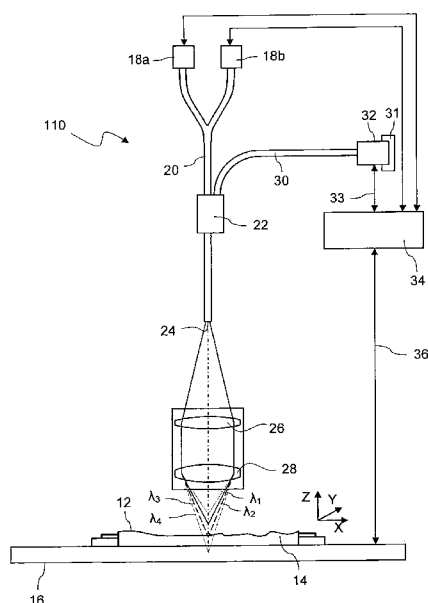


Fig. 3

(57) Abstract: A device for the measurement of the distance to an optical interface comprises a first light source (18a) generating polychromatic light. A first spectral source function (SF_a), which is associated with the first light source (18a) and describes the dependence of the intensity of the generated light on the wavelength, includes a wavelength interval in which it is non-constant. The device further comprises a second light source (18b) which also generates polychromatic light, but to which a second spectral source function (SF_b) is associated differing from the first spectral source function. An optical fiber (20) receives at one end the light generated by the light source. Imaging optics (26, 28) produces an image of the other fiber end (24) on the optical interface (12). This image is chromatically blurred along the optical axis due to chromatic longitudinal aberration of the imaging optics. A sensor (32) measures the intensity of light reflected from the optical interface (12). An evaluation unit (34) calculates the wavelength of the reflected light from the intensity measured by the sensor using the first and the second spectral source functions (SF_a , SF_b), and from the wavelength the distance to the optical interface.

DEVICE FOR CONTACTLESS DISTANCE MEASUREMENT

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a device for contactless measurement of the distance to an optical interface which reflects at least a portion of light impinging on it. In particular, the invention relates to such devices which are capable of determining a surface topography of the interface.

2. Description of the Prior Art

In many fields of technology it is necessary to measure without contact the distance to a point on the surface of an object to be analyzed. Particularly when the surface topography is intended to be determined from a plurality of such measurements, the distance measurement must be carried out with high speed without compromising the measurement accuracy.

Optical measurement methods are particularly suitable for such measurement tasks. In a known method, which is also carried out for example in CD players and is sometimes referred to as an autofocus method, a monochromatic light source generates light which is collimated and, via an axially mobile lens, focused onto the surface to be analyzed. If the focal point of the mobile lens lies exactly on the surface, then a considerable part of the light will be reflected back by the surface. In order to measure the distance, the mobile lens is moved until an intensity maximum can be measured. The distance to the surface is then obtained by taking into account

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the movement setting of the mobile lens for which the maximum was measured.

A disadvantage of this known method is that the lens cannot be moved arbitrarily fast, and therefore only relatively low measurements speeds are achievable. Intensity variations may furthermore occur owing to surface roughness of the surface to be analyzed, which make it more difficult to record the intensity maximum. For these reasons, measurement frequencies of more than 100 Hz cannot be achieved with this moving lens autofocus method.

An article by Chr. Dietz and M. Jurca entitled "Eine Alternative zum Laser", Sensormagazin No 4, 3rd November 1997, pages 15 to 18, discloses a method of optical distance measurement in which white light generated by a halogen or xenon lamp is guided through a glass fiber to a measuring head. The measurement head contains an objective with strong longitudinal chromatic aberration. The objective images the end facet of the glass fiber at a short range on a reduced scale. The chromatic aberration gives rise to a wavelength-dependent focal length for this imaging.

If there is an optical interface in the focal length range of the objective, then, owing to the wavelength-dependent focal length of the objective, only light with a very particular wavelength will generate a sharp focal point on this interface. Correspondingly, only the reflection of light with this wavelength will be imaged sharply again on the fiber facet and coupled into it. At the opposite end of the fiber, the light guided back is extracted and analyzed in a spectrograph. Each wavelength at which a local maximum of the spectral intensity distribution occurs then corresponds to a light reflecting optical interface.

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This known method thus also makes it possible to analyze the thicknesses of one or more optically transparent layers simultaneously. A disadvantage of this known method is that only a relatively small portion of the light generated by the light source can be coupled into the fiber. This leads to a low signal-to-noise ratio, which increases the demands on the spectrograph. When using a spectrograph, furthermore, it is generally not possible to achieve a high measurement resolution together with a high measurement frequency. The currently available devices of this type therefore have a measurement frequency of less than 20 kHz. Another disadvantage is that suitable spectrographs are expensive and represent a major part of the total price of such measurement devices.

EP 1 117 129 A2 discloses a semiconductor wafer inspection machine in which a white light source illuminates a spinning disk 44 having many pinholes. The spinning disk is imaged on the wafer by an objective displaying strong longitudinal chromatic aberration. The pinholes of the rotating spinning disk 44 form a plurality of bright spots that are images of the pinholes and rotate over the wafer surface. Light reflected from the wafer surface passes through the pinholes towards a beam splitter cube which splits the light reflected from the wafer surface into two portions. Each of the two portions passes through a spectral filter and finally impinges on a monochrome TV camera. The signals provided by the two TV cameras are evaluated in a manner which requires the knowledge of the spectral characteristics of the light source.

WO 2005/108919 A1, which corresponds to US 2008/0030743 A1, discloses a measurement device comprising an objective having a high chromatic aberration and two LEDs as light sources. Light reflected from a surface to be measured is guided to-

wards a wavelength dependent beam splitter which directs the light, depending on its wavelength, to two photodetectors. An evaluation unit computes the distance to the surface using the difference of the signals generated by the two
5 photodetectors.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a device for contactless measurement of the distance to an optical interface enabling a high measurement frequency without
10 compromising the measurement accuracy.

According to a first aspect of the invention this object is achieved by a measurement device comprising:

a) a first light source configured to generate polychromatic light,

15 wherein a first spectral source function, which is associated with the first light source,

- describes the dependence of the intensity of the light generated by the first light source on the wavelength, and

20 - includes a wavelength interval in which it is strictly monotonically increasing or decreasing,

b) a second light source (18b) configured to generate polychromatic light,

25 wherein a second spectral source function, which is associated with the second light source,

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- describes the dependence of the intensity of the light generated by the second light source on the wavelength,
 - is strictly monotonically increasing or decreasing within the wavelength interval and
 - differs from the first spectral source function,
- c) an optical fiber, in particular a single mode fiber, having one end configured to receive the light generated by the light source and an opposite end forming a fiber facet,
- d) imaging optics having an optical axis and being configured to produce an image of the fiber facet on the optical interface, wherein said image is chromatically blurred along the optical axis due to chromatic longitudinal aberration of the imaging optics,
- e) a single sensor configured to measure the total intensity of all the light, which has wavelengths within the wavelength interval, is reflected from the optical interface and is coupled back into the device,
- f) an evaluation unit which is configured to calculate
- the wavelength of the reflected light from the intensity measured by the sensor using the first spectral source function and the second spectral source function, and
 - the distance to the optical interface from the wavelength of the reflected light.

The measurement device according to the invention does not require a spectrograph or a wavelength selective beam split-

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ter for determining the wavelength of the reflected light. Instead, the wavelength of the reflected light is derived from simple intensity measurements using a single photodiode or another type of intensity sensor. Such sensors can measure
5 the intensity extremely fast so that measurement frequencies of 100 MHz are feasible. The use of a photodiode as sensor is also advantageous because photodiodes have a very large dynamic range so that it is possible to use a wide wavelength interval which translates into a large axial measurement
10 range. As a matter of course, two or more sensors may be used instead, but then the different wavelengths will not be distributed among the sensors, as is the case in the prior art.

The provision of two different spectral source functions is advantageous because this makes it possible to obtain two
15 measurement values for each distance measurement. The wavelength of the reflected light can then be determined from the ratio or the difference of the two measurement values. The absolute intensity of the reflected light, which may depend on the reflectivity of the optical interface and other transient effects, has no impact on the distance measurement if
20 two different spectral source functions are used.

The invention has furthermore the advantage that the light sources do not have to provide a constant spectral source function, as it is required with the conventional white light
25 source approaches. This makes it possible to use cheap but highly effective light sources having a relatively broad emission spectrum, such as LEDs. With such light sources the light can be coupled with small insertion losses into the optical fiber and may be used for the distance measurement.
30 This is in contrast to the conventional white light source approaches in which only a very small fraction of the light generated by the light source can actually be used for the

measurement. Thus the measurement device makes it possible to direct much more light on the optical interface to be measured. This has a positive effect on the measurement accuracy and reliability of the device under varying ambient conditions. Apart from that also surfaces having a low reflectivity can be measured with the device according to the invention.

LEDs and other suitable light sources usually have a maximum in their spectral source function which describes their emission spectrum. Often the spectral source function is also at least substantially symmetrical with respect to this maximum (i.e. a bell shaped spectrum). Then it is possible to select the light sources such that more than one half of the first spectral source function and more than one half of the second spectral source function overlap within a wavelength interval which is used for the distance measurements. Within such an interval one spectral source function strictly monotonically increases, and the other spectral source function strictly monotonically decreases.

However, in general it is not required that the spectral source functions are either exclusively strictly monotonically increasing or decreasing within the used wavelength interval. It suffices that the spectral source functions are non-constant and different. For example, spectral source functions may be used that have one or more maxima or minima within the used wavelength interval.

The sensor has to be capable of distinguishing whether light measured by the sensor has been generated by the first or by the second light source. The simplest way to achieve this is to configure the first source and the second source such that they alternately generate polychromatic light with the two

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different spectral source functions. This corresponds to a time division multiplexing approach.

Since the first light source and the second light source do not simultaneously generate light according to this approach, it is possible to combine their function in a single light emitting device which is controlled such that it alternately produces polychromatic light having the first spectral source function and the second spectral source function. In the case of LEDs this is often readily possible since the centroid of the emission spectrum usually depends on the working current. Other types of LEDs are capable of producing different light source functions (spectra) when a suitable control signal is applied. It is furthermore possible to use laser diodes having an emission spectrum which can likewise be adjusted over large ranges. With laser diodes, the losses when injecting into an optical fiber can furthermore be kept even smaller than in the case of LEDs.

However, also other multiplexing approaches such as frequency, code or polarization multiplexing may be used instead or additionally. Then the first light source and the second light source are configured to simultaneously generate polychromatic light having different pulse rates and/or pulse codes and/or different states of polarization.

Under certain conditions, for example if the measurement range is exceeded, the reflected light contains small portions of light having wavelengths that are outside the specified wavelength interval used for the measurement. Such portions of light will be measured by the sensor and may impair the measurement accuracy. In order to prevent such light portions from being measured by the sensor, a spectral band-pass filter may be provided that blocks light having a wavelength

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which is outside the wavelength interval which is used for the distance measurement. Any spectral band-pass filter may be used to this end, for example a combination of a low-pass and a high-pass filter.

- 5 A very effective band-pass filter having extremely steep filter slopes may be realized by a spectral filter comprising an optical grating and an aperture stop. The aperture stop has an aperture which is determined such that light having a wavelength which is outside the wavelength interval used for
10 the distance measurement is blocked by the aperture stop, and light having a wavelength which is inside the wavelength interval used for the distance measurement is allowed to pass through the aperture. If the aperture is adjustable, the band-pass limits may be easily adjusted.
- 15 For producing the first and second spectral source functions, the first and second light sources may each comprise a light emitting device, wherein the emission characteristics of the light emitting devices are different. Such different emission characteristics are often observed even with "identical"
20 light emitting devices as a result of manufacturing tolerances.

Alternatively or additionally, the first and second light sources may each comprise identical light emitting devices, but different spectral filter elements are associated with
25 each light emitting device, and these spectral filter elements define the first and second spectral source functions.

In one embodiment at least one further optical fiber is arranged such that light which is reflected from the optical interface is focused by the imaging optics on a facet of the
30 at least one further optical fiber. In this way it may be

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possible to collect more of the reflected light. This has a positive effect on the signal-to-noise ratio and thus the measurement accuracy.

The principle of determining the wavelength on the basis of
5 two independent intensity measurements may also be inverted in the sense that two different spectral source functions are associated with the light source, but two different spectral sensor functions are associated with the sensor. This will result in a device for the contactless measurement of the
10 distance to an optical interface according to a second aspect of the invention. Such a device comprises:

- a) a light source configured to generate polychromatic light,
- b) an optical fiber having one end configured to receive
15 the light generated by the light source and an opposite end forming a fiber facet,
- c) imaging optics having an optical axis and being configured to produce an image of the fiber facet on the optical interface, wherein said image is chromatically
20 blurred along the optical axis due to chromatic longitudinal aberration of the imaging optics,
- d) a first sensor configured to measure the intensity of light which is reflected from the optical interface,

wherein a first spectral sensor function, which is associated with the first sensor,
25

- describes the dependence of an output signal of the first sensor on the wavelength of the reflected light impinging on the first sensor and

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- includes a wavelength interval in which it is strictly monotonically increasing or decreasing,
- e) a second sensor configured to measure the intensity of light which is reflected from the optical interface,
- 5 wherein a second spectral sensor function, which is associated with the second sensor,
 - describes the dependence of an output signal of the second sensor on the wavelength of the reflected light impinging on the second sensor,
 - 10 - is strictly monotonically increasing or decreasing within the wavelength interval, and
 - differs from the first spectral sensor function,
- f) an evaluation unit which is configured to calculate
 - the wavelength of the reflected light from the intensities measured by the first sensor and the second sensor using the first spectral sensor function and the second spectral sensor function, and
 - 15 - the distance to the optical interface from the wavelength of the reflected light.

20 The advantages mentioned above with regard to the first aspect apply here as well. Thus also this device enables very high measurement frequencies without compromising the measurement accuracy. In contrast to prior art solutions the lateral resolution is much higher because a very small optical
25 fiber facet is imaged on the optical interface so that the measuring spot is extremely small in the lateral dimensions (i.e. perpendicular to the optical axis).

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The light source may have a spectral source function describing the dependence of the intensity on the wavelength which is not constant within the wavelength interval. This makes it possible to use a wide variety of highly effective, cheap and reliable light sources, for example LEDs. It is not even necessary to know exactly the spectrum generated by the light source.

In order to obtain two different spectral sensor functions it is possible to use sensors having different non-constant spectral response characteristics which determine the first spectral sensor function and the second spectral sensor function.

Alternatively or additionally, the device may comprise a beam splitter having a wavelength depending beam splitting ratio which determines the first spectral sensor function and the second spectral sensor function.

Alternatively or additionally, a spectral filter element may be arranged in the beam path which is associated with the first sensor and determines the first spectral sensor function.

In all embodiments it may be envisaged to use a single mode fiber as optical fiber. This is made possible because highly effective light sources such as LEDs on one hand and highly sensitive intensity sensors such as photodiodes may be used. The use of a single mode fiber has the advantage that the end facet is much smaller than is the case with multimode fibers. Consequently, the lateral resolution and also axial resolution will be improved by a factor of about 10.

It should further be mentioned that the invention may also be realized without an optical fiber having one end configured

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to receive the light generated by the light source and an opposite end forming a fiber facet which is imaged by the imaging optics. The light then propagates in free space; additional optical elements such as mirrors and lenses may then
5 be required. The applicant reserves the right to broaden the claims in this respect.

Subject of the present invention is also a method which comprises the following steps:

- 10 a) generating polychromatic light whose spectrum has at least one wavelength interval within which a spectral function, describing the dependence of the intensity on the wavelength, is strictly monotonically increasing or decreasing,
- 15 b) focusing the light onto the interface with the aid of optics, the focal plane of which is wavelength-dependent,
- c) measuring the intensity of the light which is reflected at the interface,
- 20 d) calculating the wavelength of the reflected light from the intensity measured in step c), by using the spectral function,
- e) calculating the distance to the interface by using the wavelength calculated in step d).

Light sources whose spectrum can be shifted as a function of
25 time, and preferably periodically, may be used, for example, to increase the available wavelength interval and therefore the recordable measurement range. In order to be able to derive a wavelength from the measured intensity, it is merely

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necessary to know the spectral function which the light emitted at the time of measuring the intensity instantaneously has.

If the light is directed according to the invention onto a body which has a plurality of reflecting optical interfaces, then the sensor only measures a total intensity which can no longer readily be allocated to different wavelengths, as is the case with conventional white light measurement methods. With the aid of a few additional measures, however, the distances to a plurality of optical interfaces, and therefore in particular the thicknesses of transparent layers, can also be determined very simply and rapidly with a high measurement accuracy by the method according to the invention.

When the distance to $N \geq 2$ at least partially reflecting optical interfaces is intended to be measured, as long as the distances do not lie too close together (i.e. if the layer thicknesses are not too small) then a plurality of measurements, in particular $2N$ measurements, may be carried out separately from each other according to steps a) to e).

If the difference between the distances is on the one hand very small, but on the other hand may also be very large, then very many measurements would be necessary in order to measure the distance to both interfaces. In a preferred configuration, therefore, a coarse preliminary measurement of the distance between the interfaces is carried out for preselection of the light. In this way, the number of measurements required overall can be reduced considerably.

The preliminary measurement may for example be carried out with preliminary light whose wavelength interval, within which a spectral function describing the dependency of the

intensity on the wavelength is strictly monotonically increasing or decreasing, has a width that is larger than the width of the wavelength intervals from which the preselection is made. In this way, it is possible to determine approximately where the optical interfaces are by a few coarser measurements. In a second measurement cycle, the wavelengths corresponding to these interfaces are then determined with the aid of light whose wavelength interval used is narrower and therefore allows a higher measurement accuracy.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention may be found in the following description of the embodiments with reference to the drawings, in which:

FIG. 1 is a schematic meridional section through a first embodiment of a measurement device according to a first aspect of the invention;

FIG. 2 shows the spectrum of an LED used as a light source in the measurement device shown in FIG. 1;

FIG. 3 is a schematic meridional section, in a representation similar to FIG. 1, of a measurement device according to a preferred embodiment, which comprises two LEDs as light sources;

FIG. 4 shows the spectrum of the two LEDs of the measurement device shown in FIG. 3;

FIG. 5 shows the spectra of a four LEDs used, in a modified embodiment, to increase the measurement range;

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FIG. 6 shows the spectra of four LEDs used, in another modified embodiment, in order to measure a layer thickness;

5 FIG. 7a shows the spectra of various light sources according to still another embodiment, in which a coarse layer thickness measurement is carried out initially;

FIG. 7b shows an enlarged detail of the spectra in FIG. 7a;

10 FIG. 8a shows the spectra according to FIG. 7a, but for the case of narrowly separated optical interfaces;

FIG. 8b shows an enlarged detail of FIG. 8a;

15 FIG. 9a shows a spectrum of a light source according to another embodiment, in which a measurement head for analyzing a layer thickness is moved in the axial direction;

FIG. 9b shows enlarged details of FIG. 9a;

FIG. 10 is an enlarged plan view of the end of the fiber bundle according to another embodiment;

20 FIG. 11 is a schematic meridional section through another embodiment of a measurement device comprising a spectral clipping arrangement using a diffraction grating;

25 FIG. 12 is a schematic meridional section through an embodiment of the invention according to a second aspect of the invention in a representation similar to FIG. 1, wherein the measurement device comprises one LED and two sensors;

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FIG. 13 is a schematic meridional section through a further embodiment which uses a spectral beam splitter instead of the Y-coupler shown in FIG. 12;

FIG. 14 is a diagram illustrating the wavelength dependent transmittance and reflectance of the beam splitter shown in FIG. 13;

FIG. 15 is a meridional section through a portion of a measurement device containing a wavelength independent beam splitter and two spectral filters.

DESCRIPTION OF PREFERRED EMBODIMENTS

1. First group of embodiments

1.1 Embodiments with one light source

In FIG. 1, a measurement device according to the invention is represented schematically and denoted in its entirety by 10.

The measurement device 10 is intended to determine the topography of a surface 12 of a specimen 14. The topography of a surface is generally supposed to mean its shape in three-dimensional space. The topography is usually described by the spatial coordinates of as many points as possible on the surface. The device 10 is not capable of determining absolute distance values, but only relative distance values which is usually sufficient for a topography measurement. However, it requires that the reflectivity of the surface 12 does not substantially change over its area. In many cases this condition is fulfilled; if this is not the case, a device according to one of the other embodiments should be used instead.

In order to analyze the topography, the specimen 14 is fastened on a travelling stage 16, which is an integral part of

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the measurement device 10 in the embodiment represented. The travelling stage 16 can be moved in translation in three orthogonal spatial coordinates X, Y, Z with a high accuracy relative to a base, which for the sake of clarity is not represented. If the specimen 14 is moved in the XY plane with the aid of the travelling stage 16, then the surface 12 of the specimen 14 can be sampled by the measurement device 10 in scanner fashion. The X and Y coordinates of the surface can be derived from the movement setting of the travelling stage 16, while the Z coordinate of the surface 12 is determined by distance measurement.

To this end the measurement device 10 comprises a light source 18, which is an LED (light emitting diode) in the embodiment shown. The light source 18 is coupled in a manner known as such into a first optical fiber 20, which guides the light through a 2:1 fiber coupler 22 to an end facet 24 of the first optical fiber 20. There, the light emerges in free space, is collimated by means of a collimator lens 26 and strikes a focusing lens 28. At least one of the lenses 26, 28 (or optionally other optical elements having a refractive power) is not chromatically corrected. Owing to the longitudinal chromatic aberration of the imaging optics formed by the lenses 26, 28, their focal length depends on the wavelength of the light passing through. In FIG. 1, this is schematically represented in various sketch lines for four different wavelengths λ_1 , λ_2 , λ_3 and λ_4 . If, for example, only the focusing lens 28 is chromatically uncorrected and consists of an optical material with normal dispersion, then short-wave light will be refracted more strongly than long-wave light. The focal length for a light with the smallest wavelength λ_1 is therefore the shortest, while the focal length for light with the largest wavelength λ_4 is the long-

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est. For lenses with anomalous dispersion, the situation is reversed.

The imaging optics thus forms an image of the end facet 24 of the optical fiber 20 which is, however, due to the longitudinal chromatic aberration, chromatically blurred along the optical axis of the imaging optics which is denoted by a dash dot line in FIG. 1.

As may be seen in FIG. 1, with the axial arrangement shown between the specimen 14 and the focusing lens 28, the image of the end facet 24 for light with the wavelength λ_3 lies exactly on the surface 12. The light forming the light spot created on the surface 12 as image of the end facet 24 is at least partially reflected. A portion of the reflected light enters the imaging optics formed by the focusing lens 28 and the collimator lens 26. In this way the light spot created on the surface 12 is imaged back onto the end facet 24 of the first optical fiber 20. The reflected light is guided through the first optical fiber 20 and enters, through the fiber coupler 22, a second optical fiber 30 which guides it to a sensor 32.

The sensor 32 thus measures the intensity of the light reflected at the surface 12. In the embodiment shown, the sensor 32 is formed by a photodiode having an almost zero spectral sensitivity, i.e. the intensity measured by the sensor 32 does not significantly depend on the wavelength of the light impinging on it. In order to reduce signal noise, the sensor 32 may be actively cooled; a Peltier cooling element is indicated by 31 in FIG. 1. Through a signal line 33, the sensor 32 is connected to an evaluation unit 34 which also drives the travelling stage 16 via a further signal line 36. Depending on the embodiment, the light source 18 may be con-

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nected via a signal line to the evaluation unit 34 (as indicated by dashes).

FIG. 2 shows the spectrum of the light generated by the light source 18. The spectrum is described by a spectral source function $I(\lambda)$ which describes the dependence of the intensity I of the generated light on the wavelength λ . The spectral source function has an approximately bell-shaped profile and is centered with respect to a middle wavelength λ_m . In a first wavelength interval between a smallest wavelength λ_1 and the middle wavelength λ_m , the spectral function is strictly monotonically increasing. This means in particular that the intensity for two neighboring wavelengths is never equal. In a second wavelength interval between the middle wavelength λ_m and a maximum wavelength λ_2 , the spectral function is strictly monotonically decreasing.

Only the second wavelength interval is used for the measurement in the embodiment shown in FIG. 1, for which reason it is indicated by a solid line in FIG. 2. Inside the second wavelength interval each intensity occurs exactly once. If only light of the wavelength λ_r is reflected from the surface 12, then the sensor 32 will measure an intensity $I(\lambda_r)$. Since this intensity does not occur a second time in the second wavelength interval, the evaluation unit 34 can uniquely determine the wavelength λ_r from the measured intensity $I(\lambda_r)$ if it knows the profile of the spectral source function $I(\lambda)$ within the second wavelength interval. The wavelength λ_r is therefore determined without any spectral decomposition of the light reflected by the surface 12. Since the intensity at the sensor 32 depends not only on the wavelength of the reflected light, but also on various other effects, for example the reflectivity of the surface 12 at the measuring point, it is not possible to deduce the wavelength properly only on the

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basis of the spectral source function $I(\lambda)$. However, since each wavelength is allocated to a specific distance due to the longitudinal chromatic aberration (this function can be determined computationally or by calibration), it is nevertheless possible to determine *relative* distances, i.e. distance changes, on the surface 12.

If the specimen with the surface 12 to be measured is moved in the X and Y directions on the travelling stage 16, then the distance between the focusing lens 28 and the surface 12 varies, so that light of different wavelengths is coupled back into the end facet 24 of the first optical fiber 20 and guided to the sensor 32. For each position (X, Y) the evaluation unit 34 determines a wavelength from the measured intensity, and then a distance from the determined wavelength.

From the relative distance values determined in this way for the respective X and Y displacement coordinates, the topography of the surface can then be determined fully.

If the sensor 32 has a spectrally varying sensitivity, then this may also be taken into account in the evaluation unit 34. From the measured intensity, the actual intensity will then be determined by using the spectral sensor function of the sensor 32.

For the distance measurement, it is recommendable not to use the entire second wavelength interval between λ_m and λ_2 . In the vicinity of the middle wavelength λ_m , the gradient of the spectral function $I(\lambda)$ is so small that variations of the measured intensity can no longer be resolved accurately enough. The same applies under certain circumstances in the vicinity of the upper cutoff wavelength λ_2 . There, the intensity of the light generated by the light source 18 is furthermore so small that it may no longer be possible to dis-

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tinguish clearly in the sensor 32 between reflected light and noise effects. For this reason, for a high-accuracy measurement, the wavelength interval should be restricted to a width $\Delta\lambda$ between $\lambda_{\min}$ and $\lambda_{\max}$ as is indicated by dashed lines in

FIG. 2.

As may furthermore be seen from FIG. 2, only one half of the spectrum can be used for the measurement since each intensity value occurs at two different wavelengths. Without restriction to a half of the spectrum, the evaluation unit 34 would no longer readily be able to determine whether the wavelength λ_r or λ_r' should be allocated to the intensity.

The restriction to one half of the spectrum may, for example, be carried out by attenuating the unused half with the aid of a highly effective spectral filter, to such an extent that it can no longer be detected by the sensor 32 after the reflection at the surface 12. Such a measure may be obviated if, on the basis of coarse preliminary measurements or other information, it is known that the surface 12 to be analyzed only requires such a small measurement range that it can be recorded with one half of the spectrum. With the aid of the travelling stage 16, the specimen 14 may then be moved from a particular direction (from above or from below in FIG. 1) along the Z axis to the measurement range. In this case, owing to the "history" of the measurement process, it is known whether the situation is close the maximum wavelength λ_1 or the minimum wavelength λ_2 of the spectrum.

If a photodiode is used as the sensor 32, then measurement frequencies in the range of more than 100 MHz are possible. Owing to the very large dynamic range of photodiodes, which is often of the order of magnitude of 10^7 , it is furthermore possible to use a very wide wavelength interval $\Delta\lambda$ of the

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light generated by the light source 18 for the measurement. The measurement range which can be covered by the measurement device 10 in the distance measurement is then correspondingly large.

5 Owing to the high light power which can be coupled into the optical fiber 20 and the high sensitivity of the photodiode used as a sensor 32, it is possible to use a single mode fiber which is particularly thin for the first optical fiber 20. In the known white light measurement methods, it is conventional to use multimode fibers in which the diameters of the core and the cladding are respectively 50 μm and 125 μm . If a fiber with only half as large a core diameter is selected, then the lateral resolution (i.e. perpendicular to the direction Z) will be improved by a factor of about 2. The core diameter of a single mode fiber for visible light is typically as small as 5 μm , so the lateral and also the axial resolution are improved in this way by a factor of about 10.

1.2 Embodiments with more than one light sources

10 In a representation based on FIG. 1, FIG. 3 shows a measurement device 110 according to another embodiment. Parts which are the same or correspond to one another are denoted by the same reference numerals.

The measurement device 110 differs from the measurement device 10 shown in FIG. 1 in that two separate light sources 18a, 18b are used and the evaluation unit 34 is configured somewhat differently.

In order to explain the function of the measurement device 110, reference will be made to FIG. 4 which shows the spectral source functions SF_a and SF_b of the light generated by the light sources 18a and 18b, respectively. There it can be

seen that the spectral source functions are mutually offset so that they partly overlap. The overlap is selected so that somewhat more than one half of one spectrum overlaps with somewhat more than one half of the other spectrum.

5 In the embodiment shown, the evaluation unit 34 drives the two light sources 18a, 18b alternately during the measurement. If the light source 18a which generates the spectral function SF_a is operated first, then the sensor 32 will measure an intensity I_a . Without additional measures, however,
10 the evaluation unit 34 cannot allocate a particular wavelength uniquely to the intensity I_a since two wavelengths λ_r or λ_r' in the spectral function SF_a correspond to this intensity. In order to resolve this ambiguity, the first light source 18a is switched off and the second light source 18b is
15 switched on. The sensor 32 then measures an intensity I_b to which the evaluation unit 34 could likewise allocate two different wavelengths λ_r or λ_r'' on the basis of the spectral function SF_b . By correlating the two measurements, however, uniqueness is established since only the wavelength λ_r can be
20 found as a possible solution in both measurements.

If the wavelength of the reflected light lies in a wavelength interval in which only one of the two spectral source functions SF_a , SF_b has a non-zero value, then uniqueness is likewise obtained since in this case one of the two measurements
25 gives a zero value, so that it is clear in which half of the spectrum of the light generated by the other respective light source the reflected wavelength must lie.

Compared with the embodiment shown in FIGS. 1 and 2, the measurement range can therefore be approximately tripled by
30 the double measurement described above. The usable wavelength

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interval $\Delta\lambda$ is therefore about 1.5 times the spectral width of one of the light sources 18a, 18b being used.

Apart from that the device 110 makes it possible to measure not only relative distances, but absolute distances. This is because, as can be seen in FIG. 4, each wavelength λ_r is associated with a unique ratio I_a/I_b . Thus the wavelength can be determined solely on the basis of the intensity ratio I_a/I_b . This ratio is not affected by variations of the reflectivity of the surface 12 or other transient effects within the device 110 which may affect the absolute values of the intensities measured by the sensors 18a, 18b.

1.3 Modifications

The device 110 explained above with reference to FIGS. 3 and 4 may be modified in a wide variety of ways. For instance, the measurements with the light sources 18a, 18b need not necessarily be carried out one after the other in the sense of time division multiplexing. Rather, simultaneous measurement is also possible if the evaluation unit 34 can uniquely allocate the intensities measured by the sensor 32 in another way to the spectral source functions SF_a and SF_b . In particular, it is conceivable to operate the light sources 18a, 18b in pulsed mode, so that it is possible to distinguish the measurement signals delivered by the sensor by means of different pulse rates (frequency division multiplexing). Instead of time or frequency division multiplexing, polarization division multiplexing may also be envisaged. In this case, it is merely necessary to ensure that the light generated by the light sources 18a, 18b has orthogonal polarization states (linear or circular). The reflected light with the orthogonal polarization states may then be re-separated with the aid of polarization optical components which are known per se, and

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delivered to two different optical sensors. In the case of linear polarization states, a simple polarization-selective beam splitter may be envisaged for this.

The measurement principle explained with the aid of FIG. 4 may also be implemented with only a single light source, if its spectrum can be varied as a function of time by a control signal. In this case, the two spectra shown in FIG. 4 will be generated alternately by the same light source. If the evaluation unit 34 drives the light source via the signal line represented by dashes in FIG. 1, then it will always know which of the two spectral source functions SF_a and SF_b it should allocate to an intensity value which has been measured at a particular time by the sensor 32.

The measurement range may in principle be extended arbitrarily by using not just two but m light sources, which generate mutually offset spectra. This is shown for $m = 4$ spectral source functions SF_a , SF_b , SF_c and SF_d in FIG. 5.

1.4 Several Optical Interfaces

So far, it has been assumed that the surface 12 is the only optical interface of the specimen 14, by which light is reflected. Sometimes, however, it may be necessary to analyze specimens 14 in which a plurality of optical interfaces are arranged behind one another and their topography needs to be determined. One application is to measure the thickness of thin transparent layers; then, so to speak, the surface topography becomes a layer thickness topography.

If the specimen 14 comprises a plurality of reflecting optical interfaces, laying within the axial measuring range of the measuring system, the effect of this is that light with a particular wavelength will be reflected at each interface. In

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the case of three optical interfaces, for example, the sensor 32 would record light having three different wavelengths. Since the sensor 32 cannot distinguish the wavelengths, it is not readily capable of establishing the fact that there are a plurality of interfaces. Rather, the sensor 32 would add up all the intensities and the evaluation unit 34 would allocate the cumulative intensity value a wavelength, and therefore a distance which in fact does not actually exist. If the distances between the above mentioned different optical interfaces are smaller than about 50 μm , interferences will appear which can be processed with Fast-Fourier-Transformation methods in order to measure directly the object thickness between the optical interfaces.

By measurement with a plurality of spectra, however, the distance to a plurality of optical interfaces can also be measured simultaneously with a method according to the invention. If, on the basis of preliminary measurements or other information, it is known that the minimum layer thickness is not less than a particular value depending on the spectra used, then in principle the method which was briefly explained for only one interface with the aid of FIG. 5 may be carried out in order to determine the distances to the individual optical interfaces. The minimum distance between two neighboring optical interfaces must satisfy the condition that the light which has been reflected by the interfaces has wavelengths that are allocated to two neighboring pairs of spectra, as is shown in FIG. 6. In this case, the wavelength $\lambda_{r,1}$ can be determined by initially carrying out two individual measurements with the spectral source functions SF_a and SF_b . The wavelength $\lambda_{r,1}$ is then obtained in the same way as was explained above with reference to FIG. 4.

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The wavelength $\lambda_{r,2}$ is subsequently determined by two separate measurements using the spectral source functions SF_c and SF_d . If the reflected wavelength $\lambda_{r,2}$ were so close to the wavelength $\lambda_{r,1}$ that it lies in the region of the spectral function SF_b , then ambiguities would arise which cannot readily
5 be resolved and lead to measurement errors.

The minimum distances described above between neighboring optical interfaces, below which the value must not lie, can be reduced commensurately as the spectral widths of the spectral
10 source functions SF are reduced. Since in principle each spectral function SF requires a separate measurement, however, even when using frequency or polarization division multiplex methods in which simultaneous measurement is possible for a multiplicity of spectral source functions, restrictions
15 of the signal bandwidth etc. may lead to the total measurement time per measurement point being lengthened and the measurement frequency of the measurement device therefore being reduced.

Assistance may be provided in this case by a coarse preliminary
20 measurement as shown in the spectra of FIG. 7a and, as enlarged details, FIG. 7b. In the preliminary measurement, a few measurements with wider first spectral source functions SF_{ga} , SF_{gb} , SF_{gc} and SF_{gd} serve to establish where there are in fact optical interfaces. If an intensity standing out from
25 the noise is measured for a first spectral function SF_{ga} , SF_{gb} , SF_{gc} or SF_{gd} , then fine measurements are appropriately carried out within the wavelength interval of the relevant spectral function with narrower second spectral source functions SF_f , which allow a high measurement accuracy owing to
30 their greater edge steepness. If there are wavelengths allocated to more than two optical interfaces within a wavelength interval of a first spectral function SF_g , these may under

certain circumstances still be resolved if the condition explained with the aid of FIG. 6 relating to the fine spectral source functions SF_f is satisfied. This is represented in FIGS. 8a and 8b.

5 FIGS. 9a and 9b show another modification of the way in which the distances to a plurality of optical interfaces can be measured with the aid of the method according to the invention. Similarly as has already been presented above with reference to the embodiment shown in FIGS. 1 and 2, the axial
10 distance between the specimen 14 and the focusing lens 28 contained in a measurement head can be varied - preferably in uniform steps. Instead of using the travelling stage 16, of course, the focusing lens 28 may be moved axially, which generally offers the advantage of lower masses to be moved. Ow-
15 ing to the adjustment of the distances between the specimen 16 and the focusing lens 28, the optical interfaces pass successively through the focal planes of the focusing lens 28 for the individual wavelengths. Mathematically equivalent to this is a description in which the distance remains constant
20 but the spectral function of the light changes stepwise or continuously. This representation is selected in FIG. 9a. The way in which a narrow spectral function SF seems to travel stepwise through the wavelength range may be seen therein. FIG. 9b shows the pairs of individual measurements in which
25 an interface has been recorded, in enlarged representations. The wavelength for this interface may then be calculated again in the manner explained above with reference to FIG. 2.

Instead of transferring the reflected light from the first optical fiber 20 into the second optical fiber 30 with the
30 aid of the coupler 22 outside the measurement head, the reflected measurement light may also be injected into the second optical fiber 30 directly after passing through the

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lenses 28 and 26. In this modification, the second optical fiber will be fed into the measurement head and arranged next to the first optical fiber so that the end facets of the two optical fibers 20, 30 are arranged as close together as possible.

FIG. 10 shows by way of example an arrangement in which a total of six second optical fibers 130 are arranged symmetrically around a first optical fiber 120, so that the end facets 124 of all the optical fibers 120, 130 lie in a common object plane of the optics consisting of the lenses 26, 28. The image of the end facets of the first optical fiber 120, which is generated by the optics on the reflecting surface 12 (or an interface in a multilayer system) is imaged back into the object plane by the optics as a light spot. This light spot may be distributed over several of the end facets of the second optical fibers 130.

If a separate sensor is allocated to each second optical fiber, then information about the shape of the light spot can also be obtained in this way. In turn, conclusions may be drawn therefrom regarding the angle of inclination of the surface 12 to be analyzed. This is because with inclined surfaces 12, the light spot becomes larger as well as more asymmetric; the azimuthal angle of the inclined face may be deduced from the asymmetry. Determination of the inclination will be particularly successful when the spectrum of the light source can be varied as a function of time by a control signal, as was explained above with reference to FIG. 4.

The signal-to-noise ratio is furthermore improved, since the end facets 124 of the second optical fibers 130 are added together to form a light entry face which is larger overall, so that more light can also be delivered to the sensors.

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Of course, it is also possible to arrange only a single second optical fiber 130 next to the first optical fiber 120. It is furthermore conceivable to use only one second optical fiber 130 and a plurality of first optical fibers 120, for example in an arrangement as shown in FIG. 10 but with the first and second optical fibers being interchanged.

1.5 Band-pass filter

In order to avoid measurement faults it has to be ensured that only wavelengths within a specified wavelength interval used for the distance measurement contribute to the intensity measured by the sensor 32. Otherwise ambiguities may occur under certain conditions. For example, the wavelength interval may be determined such it extends between the maximum values of the spectral source functions SF_a and SF_b as shown in FIG. 4. In the vicinity of the maximum values the slopes of the spectral source functions SF_a and SF_b are rather flat, and thus it may be difficult to discern whether a ratio of intensities corresponds to a wavelength within or outside the specified wavelength range. It is therefore preferable to prevent light portions having a wavelength outside the specified wavelength interval from impinging on the sensor 32.

FIG. 11 shows a measurement device denoted in its entirety by 210 which is, although it has been represented in a somewhat different way, quite similar to the device 110 shown in FIG. 3. Therefore parts which are the same or correspond to one another are denoted by the same reference numerals.

The measurement device 210 shown in FIG. 11 comprises an additional spectral band-pass filter 40 which is arranged between an end facet 42 of the second optical fiber 30 and the sensor 32. The adjustable spectral filter 40 comprises a

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first lens 44 which collimates the light which emerges from an exit facet 42 of the second optical fiber 30. In the collimated light path a diffraction grating 46 is arranged which diffracts the impinging light depending on its wavelength.

5 After passing through a second positive lens 48 the diffracted light, now as a converging light bundle, passes through an aperture stop 50 having an adjustable aperture and impinges on the sensor 32. The spectral band-pass filter 40 functions as follows:

10 The undesired wavelengths which are outside the wavelength interval used for measurement purposes are either shorter or longer than the desired wavelengths within the specified wavelength interval. As a result, light having these undesired wavelengths is either diffracted stronger or weaker
15 than light having a wavelength in the specified wavelength interval. As can be seen in FIG. 11, the stronger and weaker diffracted portions of the light will pass through the plane of the aperture stop 50 at larger distances from the optical axis. Therefore these undesired light portions can be blocked
20 by suitably selecting the diameter of the aperture such that only these undesired light portions, but not the desired light portions having wavelengths in the specified wavelength interval, are blocked.

The spectral band-pass filter 40 therefore makes it possible
25 to suppress undesired light portions that may otherwise, at least under certain conditions, distort the measurement results to some extent.

The aperture stop 50 may be formed by at least one additional sensor in which the aperture is formed. This additional sen-

sor may be used to indicate that the measurement range has been left.

2. *Second group of embodiments*

2.1 Different sensors

5 In a representation similar to FIG. 3, FIG. 12 shows a measurement device 310 according to a second aspect of the invention. Parts which are the same or correspond to one another are denoted by the same references. The measurement device 310 differs from the measurement device 110 shown in FIG. 3
10 in that the light sources and the sensor have, so to speak, exchanged their roles. More specifically, the measurement device 310 comprises only one light source 318, which generates polychromatic light. The spectral source function of the light source 318, which describes the dependence of the in-
15 tensity on the wavelength, may be non-constant within the wavelength interval used for the measurement.

Two sensors 332a, 332b having different spectral response functions are provided. Since the reflected measurement light again contains a wavelength for each reflecting optical in-
20 terface owing to the otherwise identical layout of the device, the evaluation unit 334 can uniquely determine the wavelength from the measurement signals provided by the sensors 332a, 332b. The evaluation is carried out similarly as explained above with reference to FIG. 4, except that the in-
25 tensity $I(\lambda)$ is to be replaced by the measurement signal strength $M(\lambda)$.

2.2 Wavelength selective Beam Splitter

FIG. 13 is a meridional section through another embodiment of a measurement device according to the second aspect of the

invention. The measurement device, which is denoted in its entirety by 410, differs from the measurement device 310 shown in FIG. 12 mainly in that the two sensors 432a, 432b are not connected to the branches of a Y-coupler, as is the case in the embodiment shown in FIG. 12, but to a wavelength selective beam splitter arrangement 460.

The beam splitter arrangement 460 comprises a wavelength selective beam splitting layer 462, which is arranged at an angle of 45° with respect to the optical axis. The beam splitting layer 462 may be applied on a transparent support plate or may be sandwiched between two prisms forming a beam splitter cube. The beam splitter arrangement 460 further comprises a first positive achromatic lens 464, which collimates the light guided emerging from an end facet of the second optical fiber 30. The beam splitting layer 462 is therefore at least substantially arranged in collimated light. Light transmitted by the beam splitting layer 462 is focused by a second positive lens 466 on the first sensor 432a, and light reflected from the beam splitting layer 462 is focused by the third positive lens 468 on the second sensor 432b. Unlike the measurement device 310 shown in FIG. 12, the first and second sensors 432a, 432b should have the same spectral sensitivity.

FIG. 14 shows, with a solid line, the dependency of the transmittance T of the beam splitting layer 462 on the wavelength λ . A line 474 indicates the reflectance $R = 1 - T$. Usually beam splitting layers are designed such that the transition region, in which the transmittance drops from its maximum value to the minimum value, is quite short. For the application in the measurement device 410, however, the beam splitting layer 462 is preferably designed such that this transition region is stretched, as is indicated by a broken line 472 in FIG. 14. This is because the longer the transi-

tion region of the spectral sensor functions 472, 476 is, the larger will be the available axial measurement region of the measurement device 410.

The beam splitting layer 462 is preferably designed such that
5 the transition wavelength λ_t is substantially in the middle of the spectral sensitivity range of the detectors 432a, 432b. This ensures that the spectral sensitivity of the sensors 432a, 432b is ideally used.

The measurement device 410 functions basically in the same
10 way as the measurement device 310 shown in FIG. 12. The wavelength selective beam splitting property of the beam splitting layer 462 replaces the different spectral response functions of the sensors 332a, 332b.

2.3 Spectral Filters

15 FIG. 15 shows a modified beam splitting arrangement 560 that may also be used in the measurement device 410 shown in FIG. 13. The beam splitting arrangement 560 comprises a wavelength independent 1:1 beam splitting layer, but additionally two spectral filter elements 570a, 570b which are arranged in the
20 light path between the beam splitting layer 562 and the second and third positive lenses 566, 568, respectively. The first spectral filter 570a may have a transmittance as indicated in FIG. 14 with broken line 472, and the second spectral filter element 570b may have a transmittance as indicated by line 474 in FIG. 14. Thus, the beam splitting ar-
25 rangement 560 has substantially the same effect as the beam splitting arrangement 460 shown in FIG. 13.

In an alternative embodiment one of the spectral filter elements, for example the first spectral filter element 570a, is
30 completely dispensed with. Therefore the first sensor 432a

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receives about 50% of the light reflected from the surface 12. The remaining spectral filter element 570b should be designed such that it has non-zero transmission over the entire wavelength interval which is used for the distance measurements. In this case the distance d_z to be measured is proportional to the ratio $(U_a - U_b)/U_b$ with U_a being the output signal of the first sensor 432a and U_b being the output signal of the second sensor 432b.

From the above description of the embodiments shown in FIGS. 12 to 15 it has become clear that it is possible to determine the wavelength of the reflected light, and from this the distance to be measured, by computing the ratio of two sensor signals to which different spectral sensor functions are associated. Each spectral sensor function describes the dependence of an output signal of the respective sensor on the wavelength of the reflected light impinging on the sensor. This spectral sensor function has to include a wavelength interval in which it is strictly monotonically increasing or decreasing, i.e. it is not constant. Preferably the spectral sensor functions are linear and have opposite gradients in the used wavelength interval, as it is indicated in FIG. 14 with lines 472, 474.

In the embodiment shown in FIG. 12, the spectral sensor function is equal to the spectral response function which is a property inherent to the sensors 332a, 332b. In the embodiment shown in FIG. 13 the spectral sensor functions are inherent to the wavelength dependent beam splitting layer 462 and are given by the curves 472, 474 shown in FIG. 14. Each of these two curves can exclusively be associated with one of the sensors 432a, 432b. In the embodiment shown in FIG. 15 the spectral sensor function is to be identified with the spectral filtering functions of the spectral filtering ele-

ments 570a, 570b, which are also exclusively associated with one of the sensors 432a, 432b.

2.4 Modifications

As has been explained above, the determination of the wavelength of the reflected light requires a simple computation of the ratio of the sensor signals provided by the sensors 332a, 332b or 432a, 432b. This ensures that the calculated distance is independent from the intensity of the reflected light coupled into the optical fiber 30. Preferably, however, the difference of these signals is computed and divided by the sum of the signals. This has the advantage that the measurement resolution is less affected by the strengths of the signals produced by the sensors 332a, 332b.

In order to increase the dynamic range, and also for suppressing noise and other disturbances, the light source 318 may be operated in pulsed mode, and the signals provided by the detectors 332a, 332b and 432a, 432b can be obtained using suitable lock-in amplifiers.

Furthermore, it is possible to use a plurality of light sources which are operated continuously or in pulsed mode. The pulses of the different light sources may be synchronous or may follow a code pattern.

It is also possible to provide a closed feedback loop which controls the light source 318 in such a way that it alternately generates light pulses which have an intensity such that either the first sensor 332a, 432a or the second sensor 332b, 432b receives a certain (high) light intensity. In other words, in this modification the output signals of the sensors are *constant*, and the input signals for the light source 318 vary. For determining the wavelength of the re-

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flected light the ratio of the two alternating input signals of the light source 318 is computed. This is even simpler to achieve if two or more light sources are provided. This approach has the advantage that the signal-to-noise ratio is
5 significantly improved, because the sensors can be operated within their optimum sensibility range.

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CLAIMS

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1. Device for the contactless measurement of the distance to an optical interface (12) which reflects at least a portion of light impinging on it, said device comprising:
 - 5 a) a first light source (18a) configured to generate polychromatic light,

wherein a first spectral source function (SF_a), which is associated with the first light source (18a),
 - 10 - describes the dependence of the intensity of the light generated by the first light source (18a) on the wavelength, and
 - includes a wavelength interval in which
15 it is strictly monotonically increasing or decreasing,
 - b) a second light source (18b) configured to generate polychromatic light,

wherein a second spectral source function
20 (SF_b), which is associated with the second light source,

- 40 -

- describes the dependence of the intensity of the light generated by the second light source (18b) on the wavelength,
- 5 - is strictly monotonically increasing or decreasing within the wavelength interval and
- differs from the first spectral source function (SF_a),
- 10 c) an optical fiber (20), in particular a single mode fiber, having one end configured to receive the light generated by the light source and an opposite end forming a fiber facet (24),
- 15 d) imaging optics (26, 28) having an optical axis and being configured to produce an image of the fiber facet (24) on the optical interface (12), wherein said image is chromatically blurred along the optical axis due to
- 20 chromatic longitudinal aberration of the imaging optics (26, 28),
- 25 e) a single sensor (32) configured to measure the total intensity of all the light, which has wavelengths within the wavelength interval, is reflected from the optical interface (12) and is coupled back into the device,

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f) an evaluation unit (34) which is configured to calculate

- 5 - the wavelength of the reflected light from the intensity measured by the sensor (32) using the first spectral source function (SF_a) and the second spectral source function (SF_b), and
- 10 - the distance to the optical interface (12) from the wavelength of the reflected light.

2. Device according to claim 1, wherein at least one of the group consisting of the first spectral source function (SF_a) and the second spectral source function (SF_b) has a maximum, and wherein
15 more than one half of the first spectral source function and more than one half of the second spectral source function overlap within the wavelength interval.
3. Device according to any of the preceding claims,
20 wherein the first light source (18a) and the second light source (18b) are configured to alternately generate polychromatic light.
4. Device according to claim 3, wherein the first
light source and the second light source are formed
25 by a single light emitting device (18) which is controlled such that it alternately produces poly-

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chromatic light having the first spectral source function and the second spectral source function.

5. Device according to any of the preceding claims,
wherein the first light source (18a) and the second
5 light source (18b) are configured to simultaneously
generate polychromatic light having different pulse
rates and/or pulse codes and/or different states of
polarization.
6. Device according to any of the preceding claims,
10 comprising a spectral band-pass filter (40) which
blocks light having wavelengths which are outside
the wavelength interval which is used for the dis-
tance measurement.
7. Device according to claim 6, wherein the spectral
15 filter (40) comprises an optical grating (46) and
an aperture stop (50) having an aperture which is
determined such that light having wavelengths which
are outside the wavelength interval used for the
distance measurement is blocked by the aperture
20 stop (50), and light having wavelengths which are
inside the wavelength interval used for the dis-
tance measurement is allowed to pass through the
aperture.
8. Device according to any of the preceding claims,
25 wherein the first and second light source (18a,
18b) each comprise a light emitting device, wherein

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the emission characteristics of the light emitting devices are different.

9. Device according to any of the preceding claims, comprising at least one further optical fiber (130) which is arranged such that light which is reflected from the optical interface is focused by the imaging optics on a facet of the at least one further optical fiber (130).
10. Device for the contactless measurement of the distance to an optical interface (12) which reflects at least a portion of light impinging on it, said device comprising:
- a) a light source (318; 418) configured to generate polychromatic light,
 - b) an optical fiber (320; 420) having one end configured to receive the light generated by the light source (318; 418) and an opposite end forming a fiber facet (24),
 - c) imaging optics (26, 28) having an optical axis and being configured to produce an image of the fiber facet on the optical interface (12), wherein said image is chromatically blurred along the optical axis due to chromatic longitudinal aberration of the imaging optics (26, 28),

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d) a first sensor (332a; 432a) configured to measure the intensity of light which is reflected from the optical interface (12),

5 wherein a first spectral sensor function (472), which is associated with the first sensor (332a; 432a),

10 - describes the dependence of an output signal of the first sensor (332a, 432a) on the wavelength of the reflected light impinging on the first sensor and

- includes a wavelength interval in which it is strictly monotonically increasing or decreasing,

15 e) a second sensor (332b, 432b) configured to measure the intensity of light which is reflected from the optical interface,

wherein a second spectral sensor function (474), which is associated with the second sensor (332b, 432b),

20 - describes the dependence of an output signal of the second sensor (332b, 432b) on the wavelength of the reflected light impinging on the second sensor,

- 45 -

- is strictly monotonically increasing or decreasing within the wavelength interval, and
- differs from the first spectral sensor function (472),

5

f) an evaluation unit (334) which is configured to calculate

- the wavelength of the reflected light from the intensities measured by the first sensor and the second sensor (332a, 332b; 432a, 432b) using the first spectral sensor function (472) and the second spectral sensor function (474), and
- the distance to the optical interface (12) from the wavelength of the reflected light.

10

15

11. Device according to claim 14, wherein the light source (318; 418) has a spectral source function describing the dependence of the intensity on the wavelength, wherein said spectral source function is not constant within the wavelength interval.

20

12. Device according to claim 14 or 15, wherein the first and second sensor (332a, 332b; 432a, 432b) have different non-constant spectral response char-

25

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acteristics which determine the first spectral sensor function (472) and the second spectral sensor function (474).

13. Device according to any of claims 14 to 16, comprising a beam splitter (462) having a wavelength depending beam splitting ratio which determines the first spectral sensor function (472) and the second spectral sensor function (474).
5
14. Device according to any of claims 14 to 17, comprising a spectral filter element (570a) which is associated with the first sensor (432a) and determines the first spectral sensor function.
10
15. Device according to any of the preceding claims, wherein the optical fiber (20; 320) is a single mode fiber.
15

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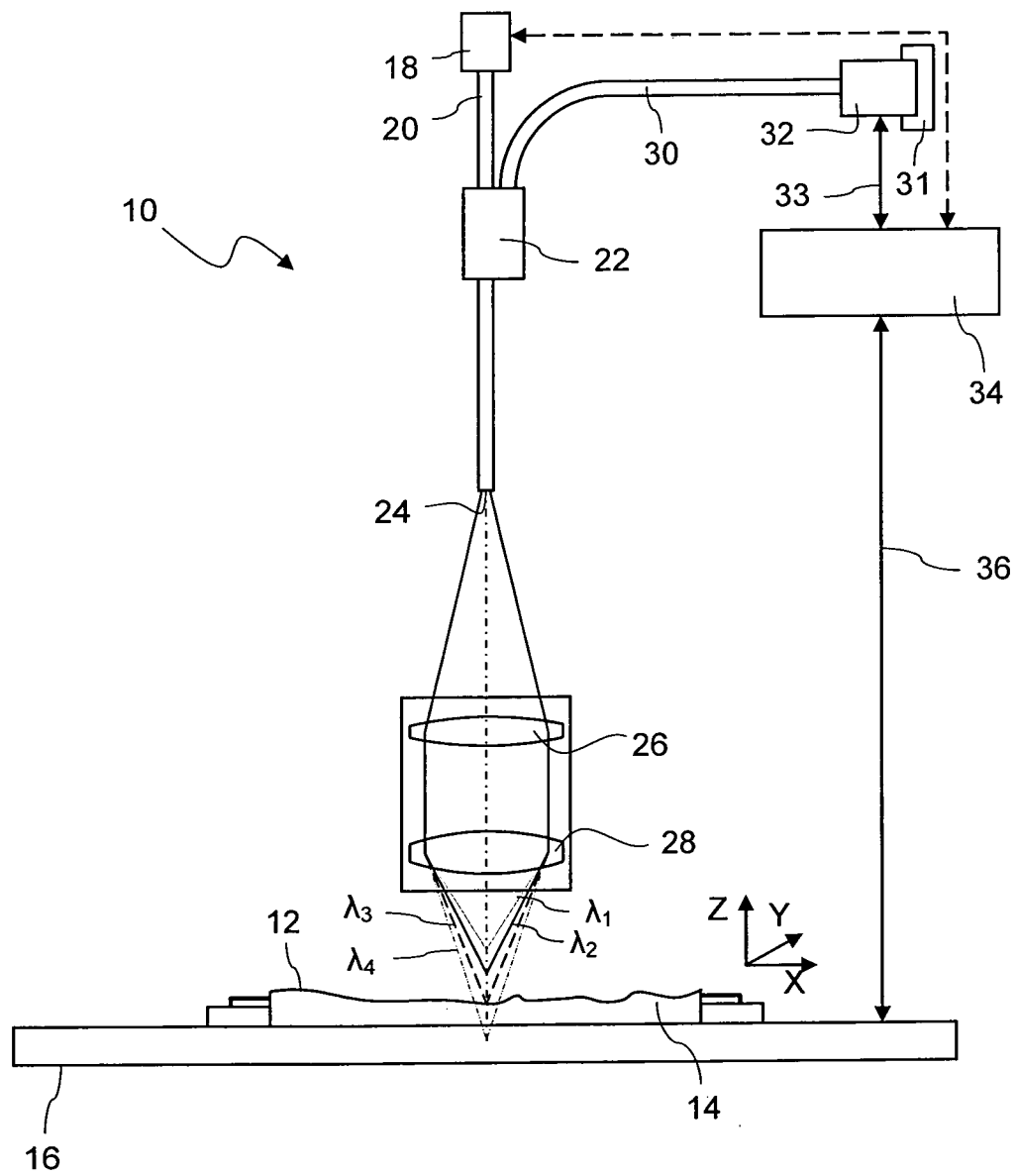


Fig. 1

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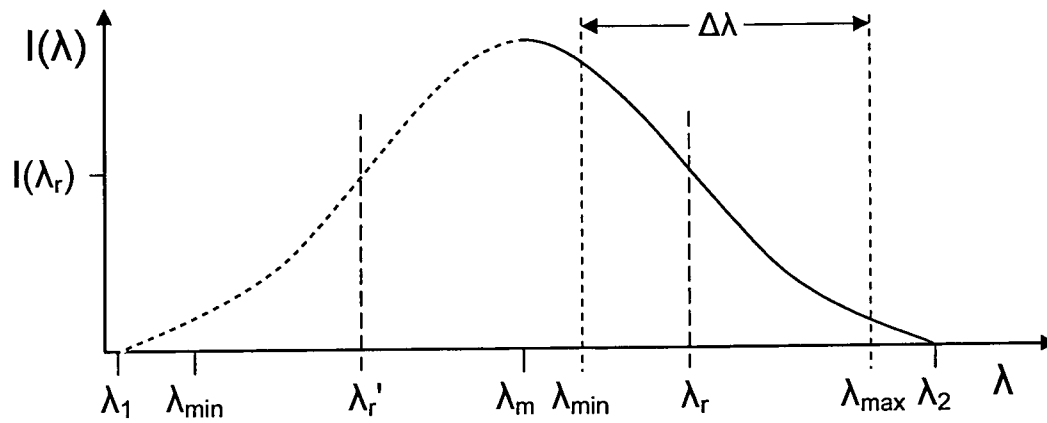


Fig. 2

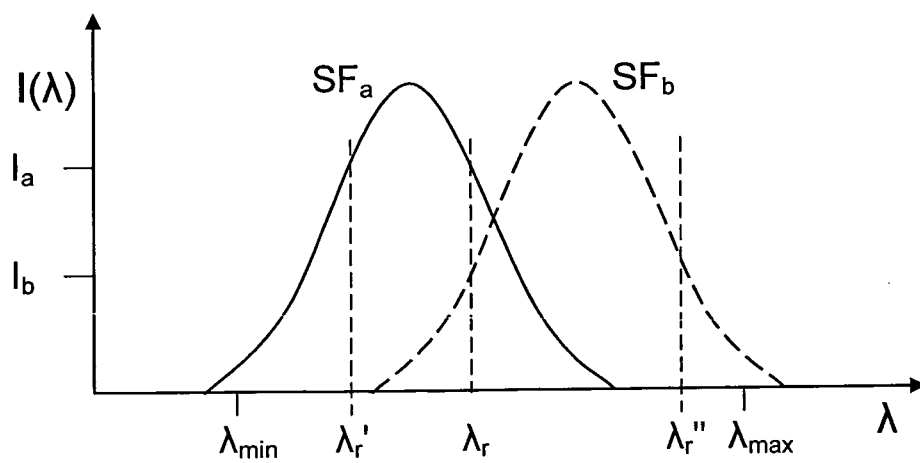


Fig. 4

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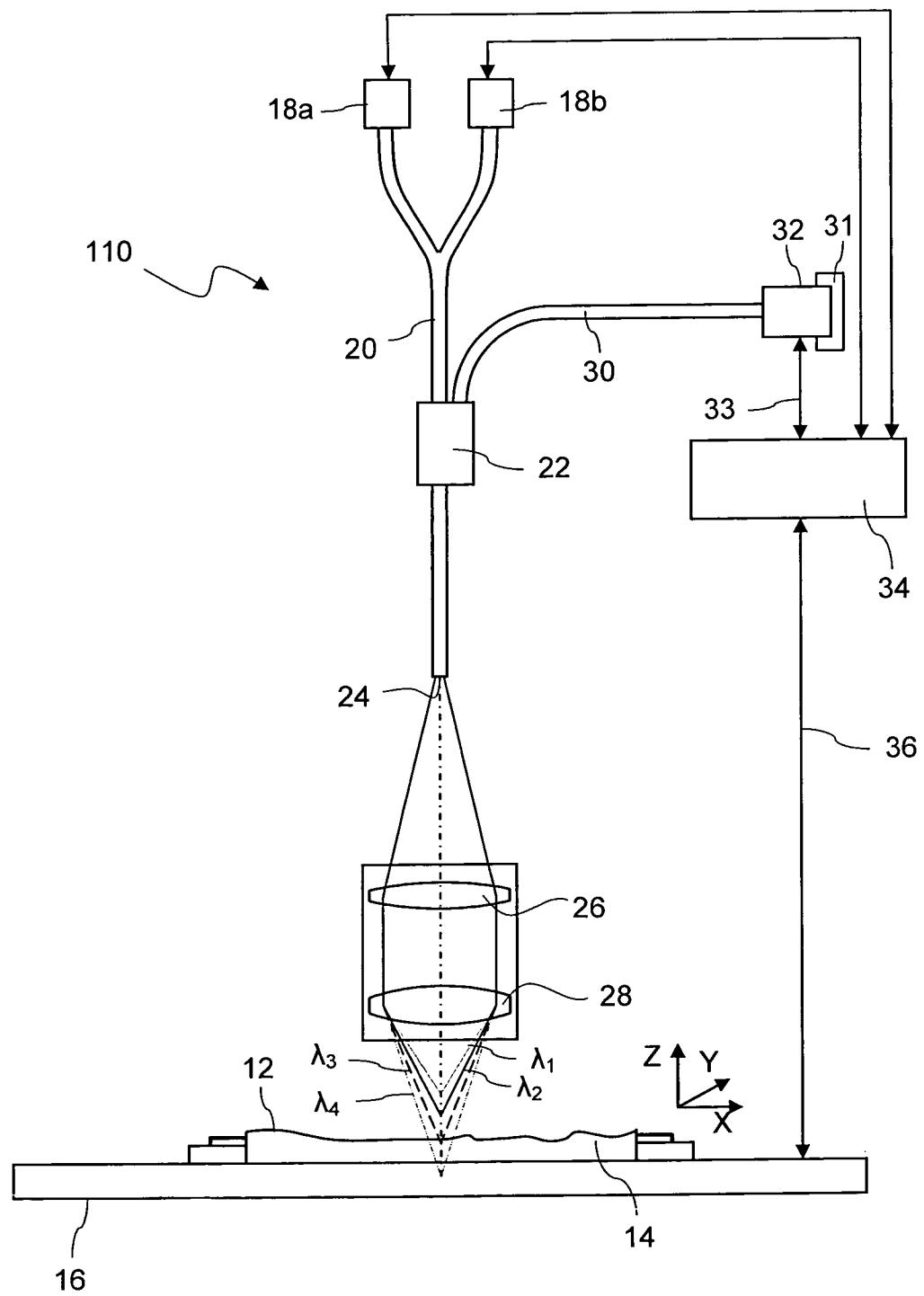


Fig. 3

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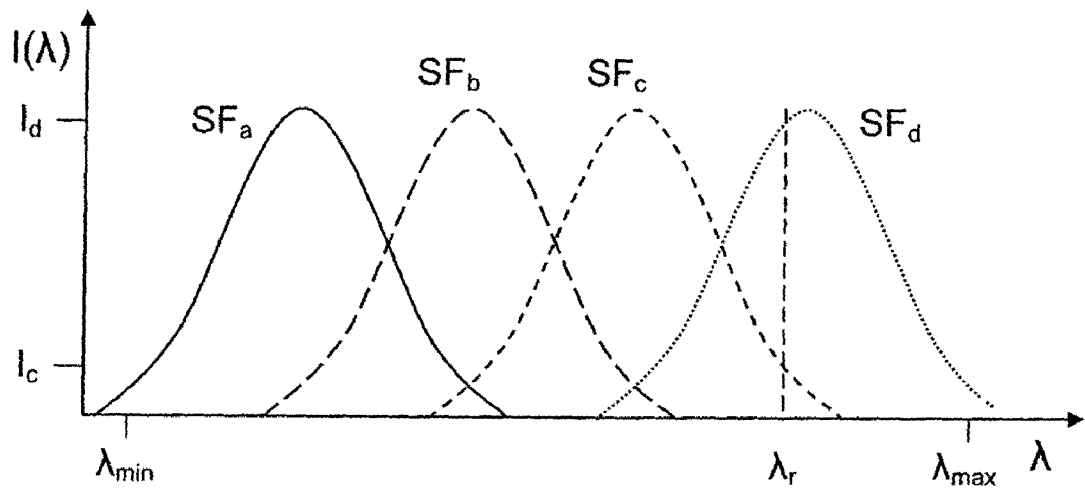


Fig. 5

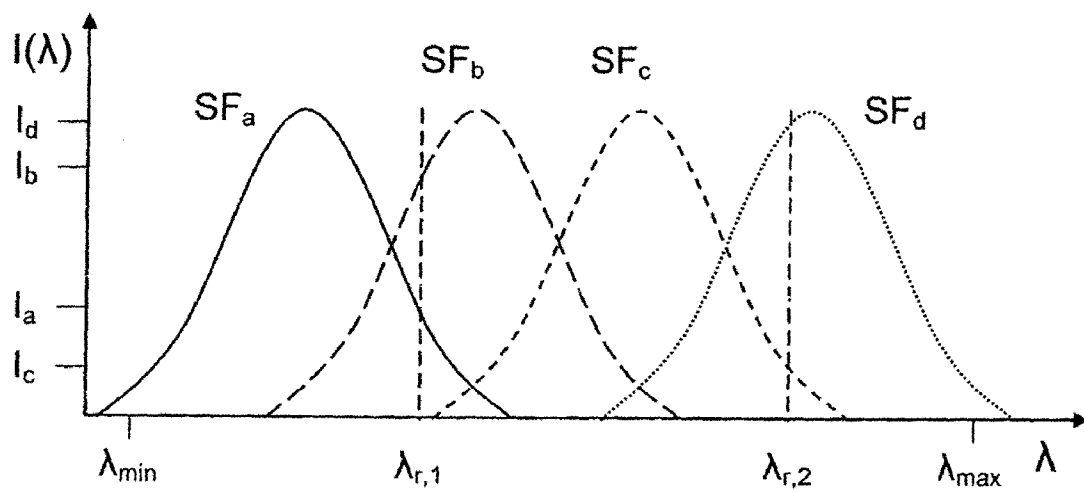


Fig. 6

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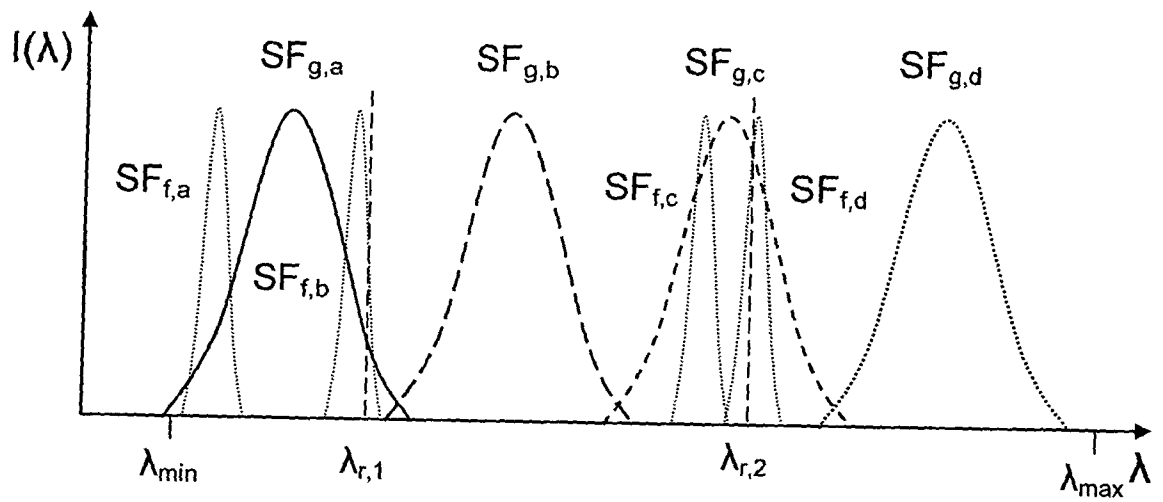


Fig. 7a

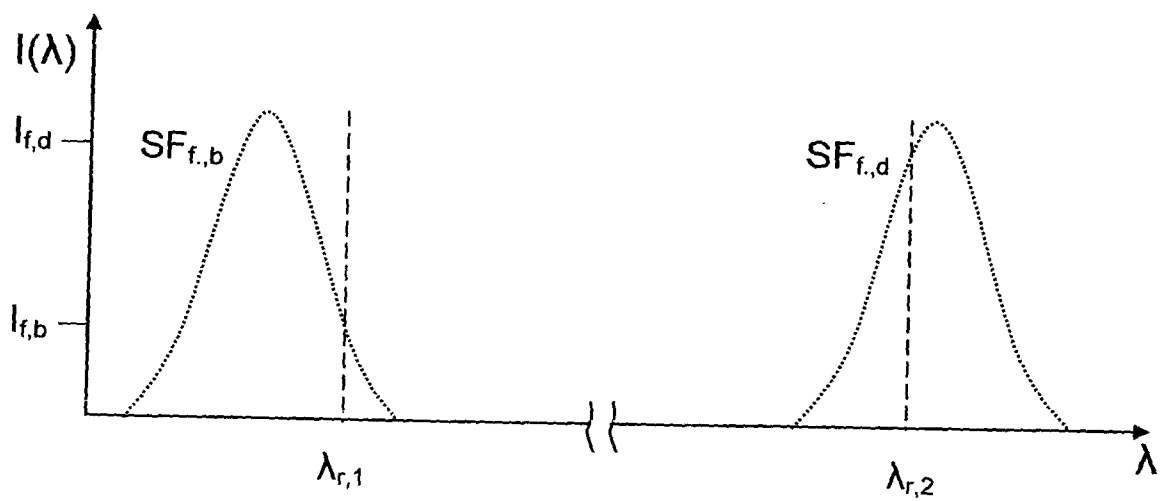


Fig. 7b

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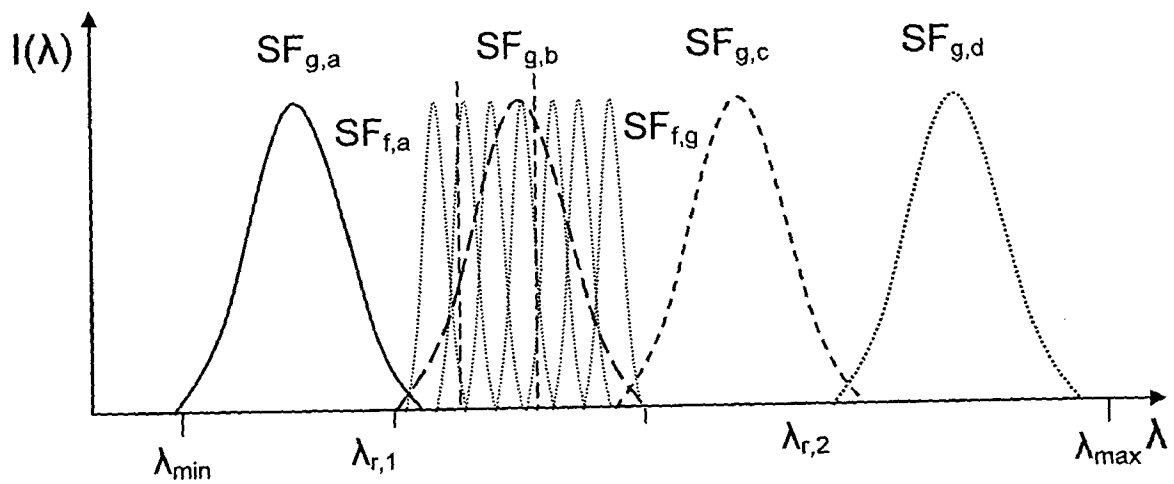


Fig. 8a

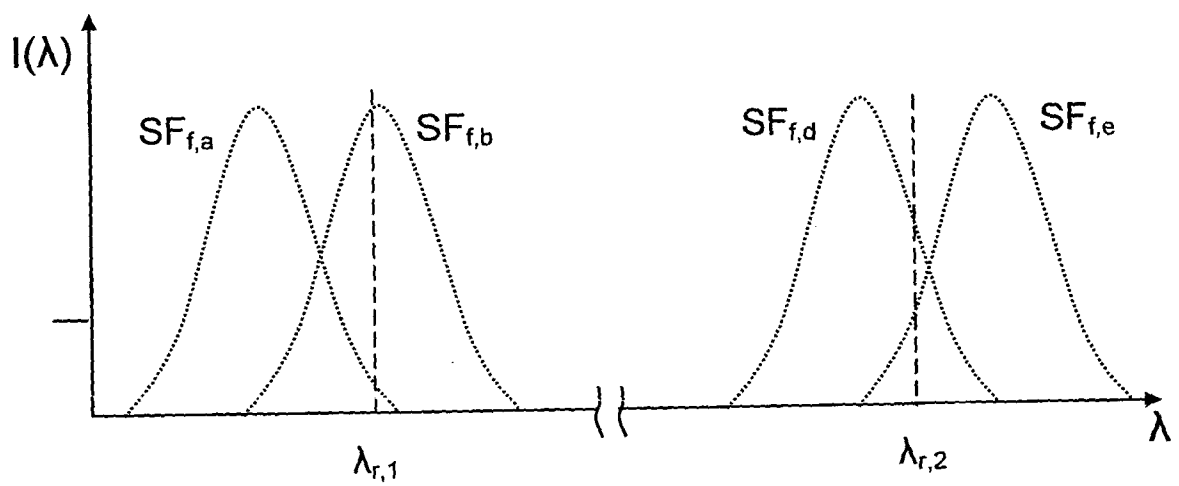


Fig. 8b

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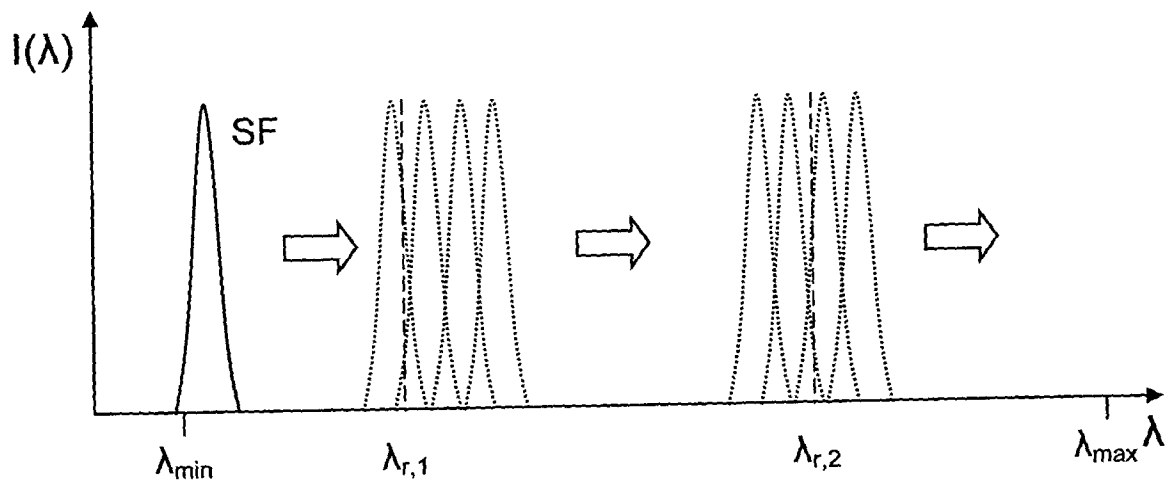


Fig. 9a

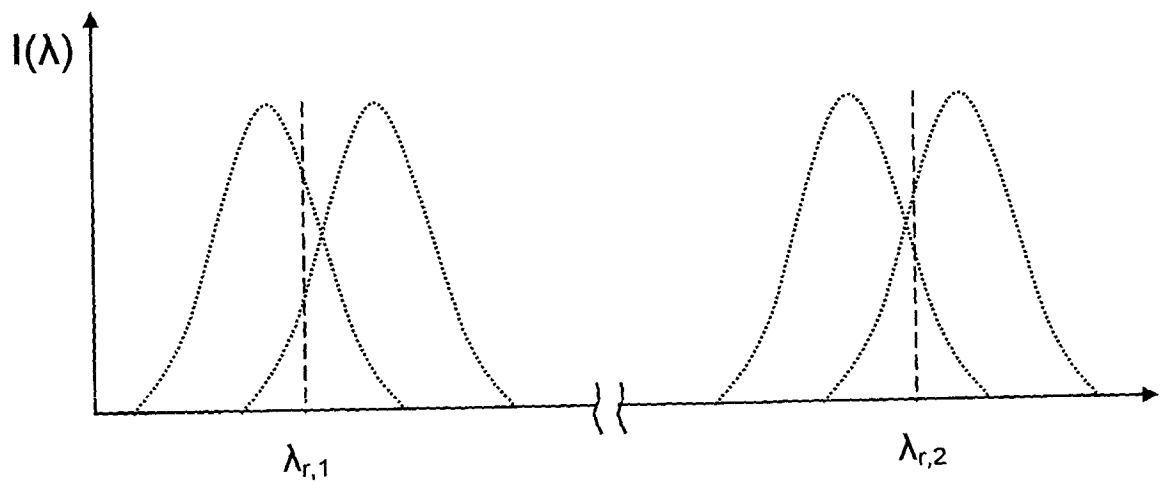


Fig. 9b

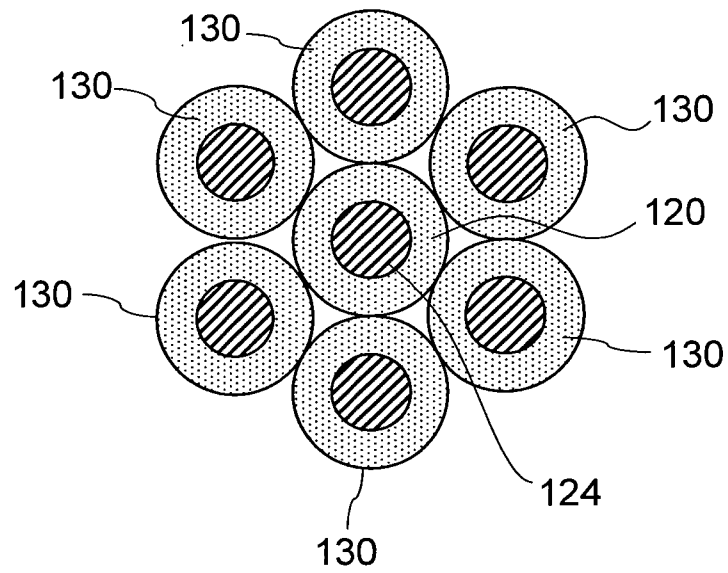


Fig. 10

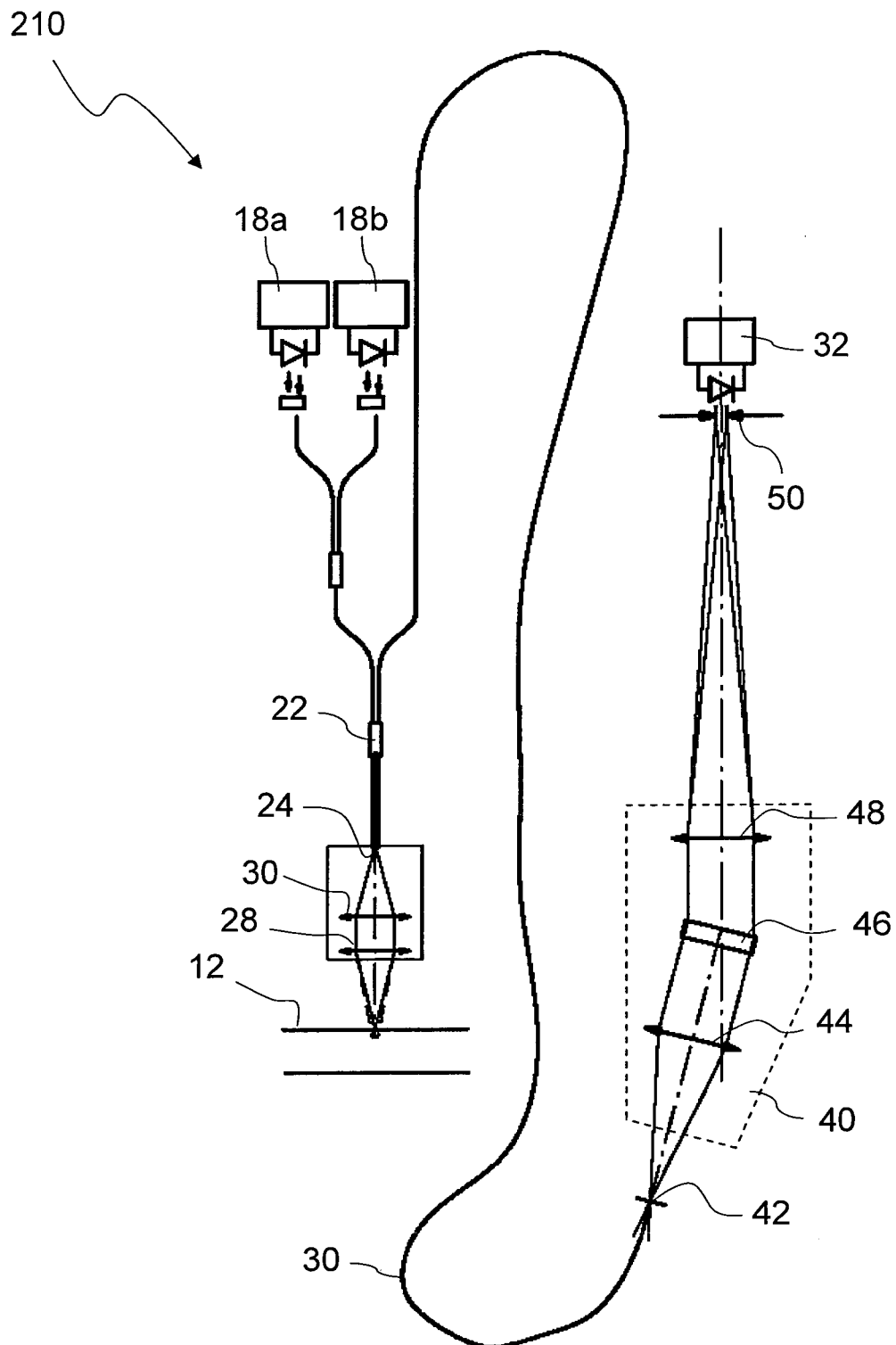


Fig. 11

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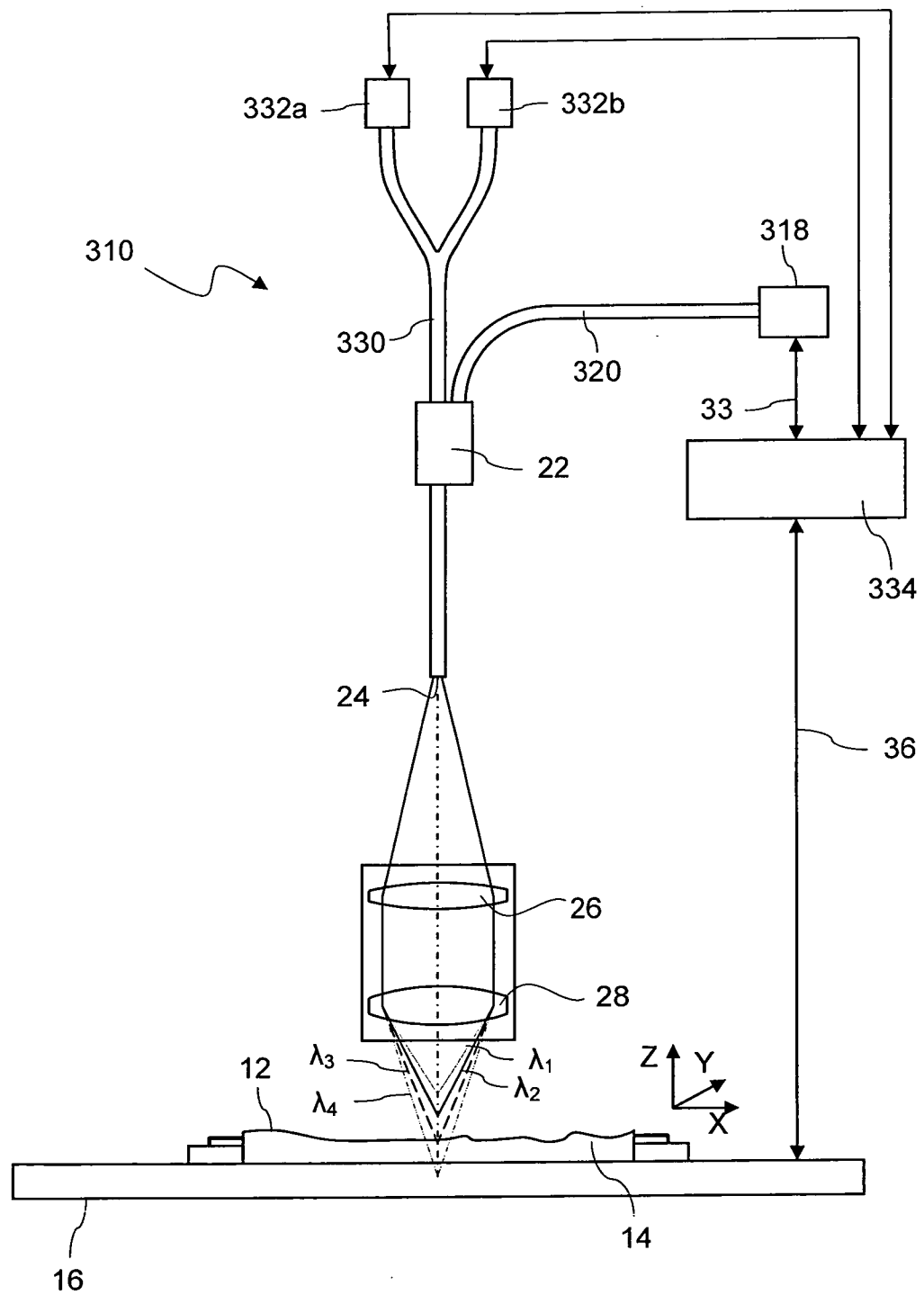


Fig. 12

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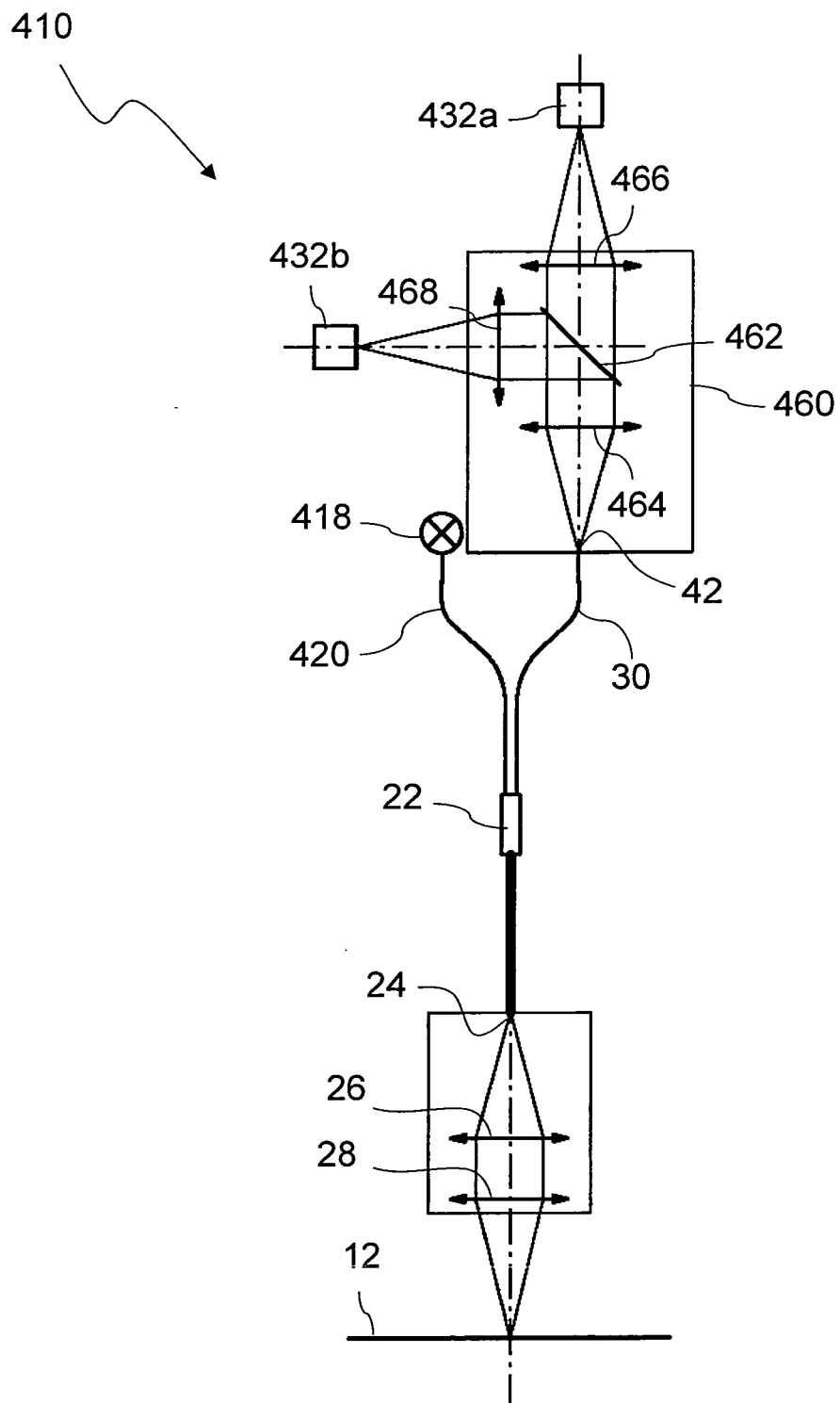


Fig. 13

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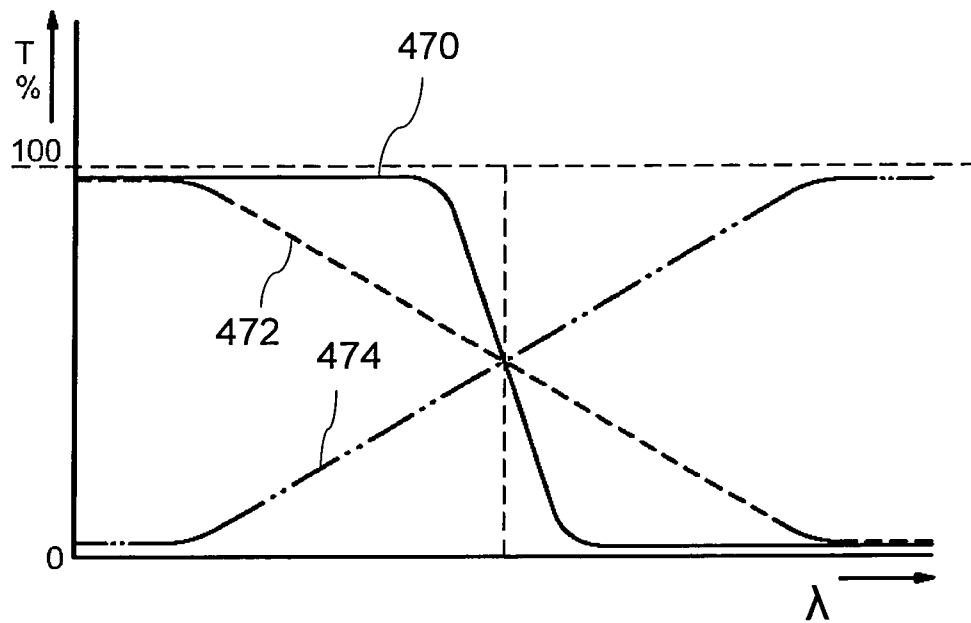


Fig. 14

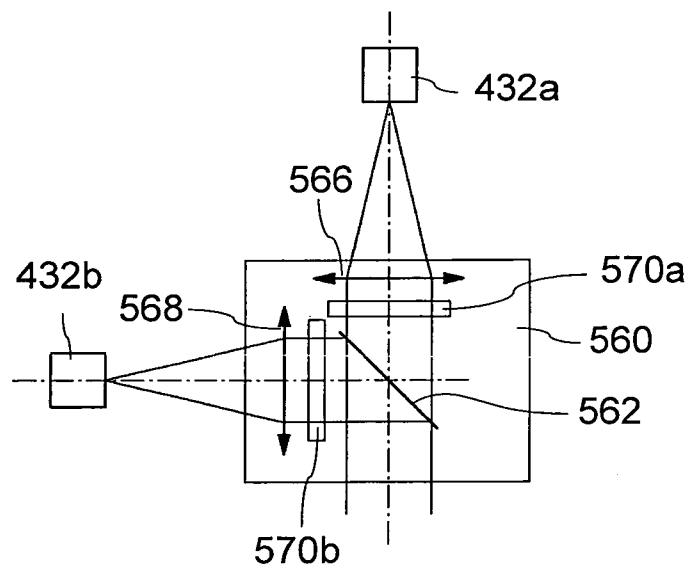


Fig. 15