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(71) Applicant: **UNIVERSITÄT STUTTGART** [DE/DE]; Keplerstr. 7, 70174 Stuttgart (DE).

(72) Inventors: **KÖRNER, Klaus**; Möllendorffstr. 80A, 10367 Berlin (DE). **CLAUS, Daniel**; Offenbachstr. 7, 70195 Stuttgart (DE). **HERKOMMER, Alois**; Droste-Hülshoff-Weg 5, 73431 Aalen (DE). **KRAUTER, Johann**; Fraubronnstr. 36, 70599 Stuttgart (DE).

(74) Agent: **MÜLLER-BORÉ & PARTNER PATENTANWÄLTE PARTG MBB**; Friedenheimer Brücke 21, 80639 München (DE).

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(54) Title: INTERFEROMETER WITH A SCHWARZSCHILD OBJECTIVE, IN PARTICULAR FOR SPECTRAL INTERFEROMETRY

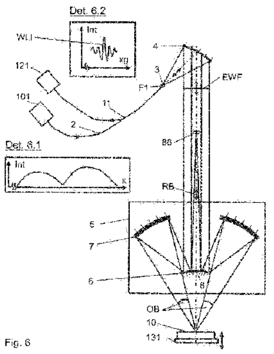

Fig. 6

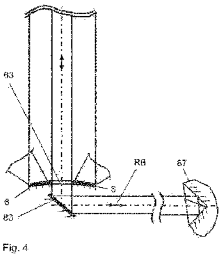

Fig. 4

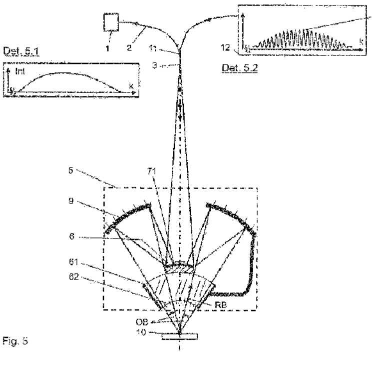

Fig. 5

(57) Abstract: The invention relates to an interferometer with a Schwarzschild objective, in particular for spectral interferometry for detecting distance, depth, profile, microprofile, shape, ripple and/or roughness of the optical path length in or on technical or biological objects, also in layer form, or an interferometer with a Schwarzschild objective for optical coherence tomography (OCT) and for the inspection of masks of semiconductor lithography in the EUV range by means of the phase shifting method. The interferometer comprises a source of electromagnetic radiation for illumination of the object, an object optical path and a reference optical path, and at least one measurement point in the object optical path, in which a surface or volume element of the object to be measured is at least approximately located. The interferometer comprises further a Schwarzschild objective with a convex primary mirror and a concave secondary mirror for illuminating and imaging at least one single object point of the object, and a detector for interferograms. A mirror surface, which is preferably a plane or concave surface, and assigned to a reference end reflector arranged in the reference optical path. The mirror surface is formed in the center region of the concave primary mirror of the Schwarzschild objective. Alternatively, a through-opening, to which a mirror below the primary mirror is assigned, is provided in the center region of the primary mirror and optionally reference end reflector is arranged downstream of said mirror. In a third configuration, in particular in case of Fizeau interferometer, the curvature of the at least one partially reflective splitter surface is such as to at least approximately correspond to the curvature of the wavefront impinging on the at least one partially reflective surface and forming a focus in the object space.

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Title: Interferometer with a Schwarzschild objective, in particular for spectral interferometry

Description

There has been an ongoing interest in obtaining information about an object form and object position by optical means without employing moving mechanical parts. One approach using spectral analysis has been proposed in the publication “Space and time variables in optics and holography: recent experimental aspects” by J.-C. Viénot, J.-P. Goedgebuer, and A. Lacourt, published in Applied Optics, Vol. 16, pp. 454-461 (1977).

Other early studies suggested the use of a dispersion-free Schwarzschild objective for the UV (Ultraviolet) spectral range, see the publication by W. Emer and J. Schwider “Ultraviolet interferometry with apochromatic reflection optics”, published in Applied Optics, Vol. 38, No. 16, pages 3516-3522, of June 1, 1999. For the extreme UV range (EUV), a Schwarzschild objective has also been advantageously used, see for example the publication of Tsuneyuki Haga, Hisakata Takenaka, and Makoto Fukuda “At-wavelength extreme ultraviolet lithography mask inspection using a Mirau interferometric microscope”, published in J. Vac. Sci. Technol. B 18(6), Nov/Dec 2000S, pp. 2916-2920. However, the thin-film beam splitter in the interferometer proposed in this publication is quite susceptible to vibrations.

Figure 2 of the laid-open patent application DE 10 2010 046 907 A1 shows a two-beam interferometer comprising a part of a Schwarzschild objective for object illumination and imaging, a downstream weak-focusing diffractive optical element with positive refractive power, and a Fresnel lens for chromatic depth splitting of foci. The arrangement allows simultaneously detecting measurement points in different depths in the object space. The refractive materials in the optical path can, however, produce dispersions that can lead to nonlinearities in the spectral wavelet. This can considerably complicate the signal evaluation.

The publication by P. Kühnhold, P. Lehmann, and J. Niehus "Dispersion optimized white light interferometer based on a Schwarzschild objective", published in Proc. of SPIE Vol. 8082, 80822Q in 2011, doi 10.1117/12.889434, describes a deep-scanning interferometric arrangement with a Pellicle beam splitter. The latter generates, however, undesirable multiple reflections and may be prone to vibrations during measurements in an industrial environment, thereby increasing the uncertainty of measurement. The Pellicle beam splitter in front of the object also considerably reduces the free working distance of the measuring system.

It is an aim of the invention to provide a compact, robust interferometric single-shot sensor suitable for commercial exploitation.

Examples of the invention may further relate to one or more of the following objects:

One object is to avoid the influence of dispersions in the interferometric optical path in order to generate spectral wavelets with a minimum of nonlinearities in the signal. This can considerably simplify the signal evaluation. A further object is to maximize the working distance in the object space of a single-shot point sensor by dispensing with a beam splitter in front of the measurement object. Another object is to minimize the spatial expansion, in particular in the transverse axis of the sensor, for example by employing optical ray design principles. Another object is to minimize spectral artifacts in short coherence interferometry or optical coherence tomography (OCT). Still other object is to provide a comparatively vibration-proof interferometer arrangement for the sensor and/or to provide an improved method for inspection of masks employed for semiconductor lithography using light in the EUV or X-ray range by using the proposed sensor. Here, a specific object relates to dispensing with the thin beam splitter in the interferometric optical path of the sensor.

Throughout the application, the term light is always used as a synonym for electromagnetic radiation from the terahertz through the infrared to the EUV range, including electromagnetic radiation in the X-ray spectral range.

An aspect of the invention relates to an interferometer with a Schwarzschild objective. The interferometer may be used for example for spectral interferometry for detecting distance, depth, profile, microprofile, shape, ripple and/or roughness of various objects, for measuring the optical path length in or on various objects, for optical coherence tomography (OCT), or for other interferometric measurements. In each case, the measurement is performed in at least one point of the measured object. The interferometer can be employed for example for inspection of masks of semiconductor lithography with radiation in the EUV range or X-ray Range or other suitable spectral range by using a phase shifting method, in particular also with a multi-point detection. The measured objects may be various technical or biological objects, including objects in a layer form.

The interferometer comprises a source of electromagnetic radiation (light source) for illuminating at least one measurement point or field of the object, at which measurement point or field a surface or a volume element of the object to be measured is located. The source may be a radiation source emitting light in a suitable spectral range, for example in the terahertz range, in the infrared range and in particularly in near infrared spectral range, in the visible range (VIS), in the ultraviolet range, in the deep ultraviolet range, in the extreme ultraviolet range (EUV) or in the X-ray range.

The interferometer has an object optical path and at least one reference optical path. In the object optical path, the at least one measurement point or field is located/arranged. The reference optical path may comprises at least one reference end reflector or at least one reference surface.

The interferometer comprises further a Schwarzschild objective and a detector for detecting electromagnetic radiation in the form of at least one interferogram intensity. The Schwarzschild objective (optionally in combination with other components) may perform splitting of the wavefront into a reference wavefront and an object wavefront. It is also possible that a component such as a splitter surface (for example a Fizeau splitter surface) in combination with the Schwarzschild objective performs the splitting of the wavefront into a reference wavefront and an object wavefront.

The Schwarzschild objective has a concave primary mirror and at least one secondary mirror for illuminating and imaging at least one single object point of the object. The primary mirror of the Schwarzschild objective has a center region, which is an annular region around the axis of symmetry of the Schwarzschild objective. The diameter of the center region can be selected depending on the specific application. The center region generally corresponds to the annular region around the axis of symmetry, which in prior art interferometers is typically not optically used, in particular not used for object illumination.

The primary mirror of the Schwarzschild objective may be modified to enable decoupling and coupling of a reference beam/reference wavefront from the input beam/input wavefront. In other words, the primary mirror of the Schwarzschild objective may be modified to perform splitting of the input wavefront into a reference wavefront and an object wavefront.

In an example, the primary mirror of the Schwarzschild objective may be modified by forming a mirror surface or a mirror in the center region of the concave primary mirror of the Schwarzschild objective. The mirror surface or mirror generally has a curvature which is different from the curvature of the primary mirror of the Schwarzschild objective. The mirror surface or mirror may be formed to be integral (i.e. in flush) with the primary mirror or at a distance (i.e. standing out) from the primary mirror of the Schwarzschild objective. A reference end reflector may be assigned to the mirror surface or mirror. The reference end reflector may be arranged downstream of the mirror surface or mirror in the reference optical path, i.e. downstream of the mirror surface or mirror in a direction of propagation of reference light in the interferometer.

Alternatively, the primary mirror of the Schwarzschild objective may be modified by forming a through opening in the center region of the primary mirror. In this arrangement, a mirror may be arranged downstream of the through opening in the reference optical path. In a standard representation of a Schwarzschild objective, the mirror may be arranged “below” below the primary mirror, i.e. on the side of the primary mirror which is away from the secondary mirror(s).

In another arrangement the splitting of the input wavefront is carried out by at least one partially reflective splitter surface. The at least partially reflective splitter surface is formed as a curved surface having a curvature at least approximately corresponding to the curvature of the wavefront impinging on the partially reflective surface and forming a focus in the object space. For example, if the Interferometer is a Fizeau interferometer, it may comprise a (transparent) reference piece having a meniscus shape (hereinafter also referred to as a meniscus). One of the curved surfaces of the reference piece serves as a Fizeau splitter surface that (partially) reflects back the impinging light bundle to form a reference bundle reflected back into the detection optical path (which also includes the reference optical path). The Fizeau splitter surface may have a curvature at least approximately corresponding to the curvature of the wavefront impinging on the Fizeau splitter surface and forming a focus in the object space.

The mirror surface formed in the center region of the primary mirror of the Schwarzschild objective or the mirror arranged downstream of the through-opening formed in the primary mirror of the Schwarzschild objective may be plane or curved, for example concave. The concave mirror surface or the concave mirror may be formed for example as a rotary paraboloid. This allows an aberration-free point mapping. The mirror surface or mirror may each be formed to be laterally smaller than the incoming wavefront (the input wavefront).

The mirror surface formed in the center region of the primary mirror of the Schwarzschild objective or the mirror arranged downstream of the through-opening formed in the primary mirror couples out light from a part of the input wavefront, so that the wavefront is split, for example in a reference and an object wavefront or, respectively, reference and object beam.

The mirror surface formed in the center region of the primary mirror or the mirror arranged downstream of the through-opening may be arranged on-axis or off-axis with respect to the axis of symmetry of the Schwarzschild objective and/or may reflect at least a part of the incoming wavefront in a direction substantially parallel to the optical axis or at an angle to the optical axis of the interferometer (which may coincide with the axis of symmetry of the Schwarzschild objective). For example, in case of the off-axis arrangement, the decoupled part of the wavefront may leave the radiation space of the incoming wavefront laterally. In the case of the on-axis surface, the decoupled part of the reference light (the reference radiation) may remain symmetrical to the optical axis (which may be coincident with the axis of symmetry of the Schwarzschild objective).

If a concave mirror surface on the primary mirror of the Schwarzschild objective is formed with an on-axis or off-axis mirror surface with respect to the axis of symmetry of the Schwarzschild objective, the light of the wavefront may be focused for example on a plane or curved reflector in the reference optical path (for example on the plane or curved reference end reflector). The focal spot may be at least approximately restricted, for example it may be a diffraction limited focal spot. It should be noted that due to the splitting of the wavefront, the diffraction-limited focal spot in the reference optical path can have a smaller numerical aperture than the image produced by the Schwarzschild objective in the object space. An arrangement with a focus on a plane reference reflector is comparatively insensitive to the tilting of the reference reflector. The reference reflector can, however, be curved, wherein both convex and concave shapes are possible. The curvature of the curved reference reflector can be used to reduce aberrations in the reference optical path within a focal field, rather than in a single focal point. Thus, a field in the object space can be measured, since a respective reference field is also provided for in the reference optical path. Preferably, the generation of a plurality of reference focal points in the reference optical path as well as a plurality of object focus points in the object optical path is accomplished thereby.

In arrangements with a reference end reflector, the reference end reflector may be arranged downstream (in the direction of reference light propagation) of the plane or concave mirror in the reference optical path. The reference end reflector may deflect the light by approximately 90 degrees. The plane or concave mirror may also serve as a reference mirror itself. However, in an interferometer assembly with a Schwarzschild objective, this may lead to a highly unbalanced interferometer. In this case, a frequency comb light source, a Fabry-Perot or a correspondingly unbalanced two-beam interferometer - for example a Michelson interferometer – may be used for bridging, i.e. for compensating, the optical path difference.

The source of electromagnetic radiation may comprise one or more point-shaped light sources or light spots, arranged for example in a one or two-dimensional array. In an arrangement with several point-shaped light sources or spots in the source of electromagnetic radiation, there may be formed several reference focal spots (for example after return of the light from the reference mirror). A confocal discrimination may be carried out for each individual reference focal spot by employing for example an associated pinhole of a pinhole array. For this purpose, the individual pinholes of the array may be slightly separated, for example by an amount that exceeds their lateral expansion at least twice.

Since the numerical aperture for the reference focal spot(s) after recoupling into the optical path by a reference mirror or a reference mirror surface is clearly smaller than the numerical aperture for the focal spot(s) formed by the object light, the Airy disks of the reference focal spot(s) formed by the reference light are significantly larger than those of the focal spot(s) formed by the object light. Thus, without confocal discrimination (for example by a fade-out as from the center of the corresponding focal spot(s) and/or using pinholes) the Airy disks of the reference focal spots would cover several Airy disks of the object focal spots and would thus greatly reduce the interference contrast and introduce crosstalk, which is detrimental to the measurement. In an example, only a small central part of the reference light focal point(s) is faded out. In contrast, the light of the object foci can essentially pass through the pinholes, as they have a much smaller diameter than the reference light focal point(s) because of their significantly larger numerical aperture.

As described above, it is possible to employ sources of electromagnetic radiation in various spectral ranges. In an example, the source of electromagnetic radiation for illuminating the object may be an X-ray light source or EUV light source, preferably in the EUV range around 12 nm to 13 nm of wavelength. With such an interferometer, masks for HL lithography can be measured with very high lateral and depth resolution.

The source of electromagnetic radiation for illuminating the object may be one or more of a spectrally broad-band source, a multispectral source, a tunable light source, and a light source with a frequency comb spectrum.

For example, the source of electromagnetic radiation for illuminating the object may be a spectrally broadband source, for example a fiber-coupled superluminescence diode or a fiber-coupled broadband laser, also known as a white light laser. In this case, the interferometer may operate as a scanning interferometer (time-domain interferometer) preferably around the optical path difference of zero. The broadband source may preferably be configured as a multispectral light source with a comb spectrum.

The radiation source may also be a tunable light or radiation source (i.e. a source with a variable wavelength), for example a tunable infrared quantum cascade laser or as a tunable terahertz radiation source so as to be able to carry out spectral interferometry without a spectrometer. To this end, it is advantageous for the radiation source to be a spatially coherent light source. With such an arrangement, swept-source spectral domain OCT, also known as swept-source Fourier domain OCT, can be carried out in the infrared and terahertz range. When using fast swept-source sources, an x-y scanner can be arranged downstream of the Schwarzschild objective in order to obtain an image, so that an area or volume measurement of the object is possible.

It is also possible to use a light source (source of electromagnetic radiation) with a frequency comb spectrum, for example a frequency comb laser. This is advantageous if the interferometer is strongly unbalanced, i.e. the optical path difference is comparatively large. There is a bridging or a compensation of the optical path difference in the interferometer.

The interferometer with a Schwarzschild objective may be configured as a spectral interferometer and/or may comprise a spectrometer arranged at the output of the interferometer in order to be able to carry out spectral interferometry. The spectrometer may be fiber-coupled. To this end, the source of electromagnetic radiation may be a multispectral source or a broadband radiation source. For example the source of electromagnetic radiation may be a broadband terahertz radiation source, so that the spectral interferometer operates in the terahertz range. With such an arrangement, spectral domain OCT, also known as Fourier domain OCT, can be carried out. The optical path difference xg in the spectral interferometer is preferably less than a thousand times the greatest wavelength in the spectrum used/detected. In this case, the optical path difference in the long-wave terahertz spectrometer can also be up to 100 mm. This requires a Schwarzschild objective with a focal length in the single-digit meter range.

Preferably, the spectrometer is configured as a single-shot system. It may preferably also be a single-shot system which, as a dispersive spectrometer, can detect the spectrum of a line or of several measurement points in one shot, i.e. at the same time. In order to obtain an image, an x-y scanner can be arranged downstream of the Schwarzschild objective, so that an area or volume detection of the object is possible.

The interferometer with a Schwarzschild objective might be a Michelson type, a Fizeau type, or a Mach-Zehnder type inteferometer. In the case of the latter, the location of the beam splitting is separated from the location of the beam unification.

Another aspect of the invention relates to a method for spectral interferometry or for spectral domain coherence tomography, comprising:

performing interferometric measurement or a spectral domain coherence tomography of an object to be measured by an optical interferometer according to any one of the aspects and examples described above, and

obtaining at least one a measuring signal, said measuring signal including at least one spectral wavelet or at least one white light interferogram;

processing the measuring signal to obtain one or more of the following characteristics of the object to be measured: distance, depth, profile, microprofile, shape, ripple, roughness, optical path length, and optical coherence tomography data. The processing of the obtained spectral wavelet or white light interferogram may be performed by methods known to the skilled person, for example using a phase shifting method.

These and other aspects will now be described in detail with reference to the following drawings, wherein:

Fig. 1 shows an exemplary interferometer with a Schwarzschild objective configured as single-shot spectral interferometer;
Fig. 2 shows another exemplary interferometer with a Schwarzschild objective configured as single-shot spectral interferometer;
Fig. 3 shows a partial view of a third example of an interferometer with a Schwarzschild objective configured as a single-shot point sensor;
Figure 4 shows a partial view of a fourth example of an interferometer with a Schwarzschild objective configured as a single-shot point sensor;
Figure 5 shows a fifth example of an interferometer with a Schwarzschild objective configured as single-shot point sensor;
Figure 6 shows a sixth example of an interferometer with a Schwarzschild objective for a time domain OCT;
Figure 7 shows a seventh example of an interferometer with a Schwarzschild objective configured as a scanning multi-point white light interferometer;
Figure 8 shows an eighth example of an interferometer with a Schwarzschild objective configured as a scanning multi-point white light interferometer; and
Figure 9 shows a ninth example of an interferometer with a Schwarzschild objective.

In the figures, same reference numerals are used for the same or similar components.

Figure 1 shows an exemplary interferometer with a Schwarzschild objective, which is configured as a single-shot spectral interferometer. The interferometer comprises a source of electromagnetic radiation, which in this case is a fiber-coupled superluminiscence diode (SLD) 1 emitting light in the visible range (VIS). The light from the fiber-coupled superluminescence diode (SLD) 1 exits the single-mode fiber 2 at its output 3 into the free space. The spectrum of the superluminescence diode 1 in the wavenumber domain (k domain) is symbolically shown in **detail 1.1**. The output 3 of the single-mode fiber 2 is arranged in the focal point F1 of a collimating mirror 4, so that a plane input wavefront EWF is formed. The plane input wavefront EWF enters a Schwarzschild objective 5 with a convex primary mirror 6. A concave on-axis coupling mirror 8 (as an example of a mirror surface formed in the central region of the primary mirror 6) for coupling and decoupling reference light and forming a focused reference beam bundle is located in the center of the convex primary mirror 6. The coupling mirror 8 for coupling and decoupling is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5. This arrangement causes splitting of the input wavefront EWF, with an inner annular region or part forming a reference wavefront or beam and an outer annular region or part forming an object wavefront or beam. The light reflected at the coupling mirror 8 reaches the miniaturized plane mirror 86, which is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5 and serves as a reference end mirror. This is shown again in **detail 1.2**. The light in the outer region of the split input wavefront EWF reaches the concave secondary mirror 7 after reflection at the convex primary mirror 6, where focusing as an object bundle OB in the object space onto the object 10 takes place. The object light reflected back from the object 10 passes through the concave secondary mirror 7, the convex primary mirror 6, and the collimating mirror 4 into the single-mode fiber 2, into which the reference light from the reference optical path has entered as well and object light and reference light come to interference. After decoupling at the Y-switch 11, the interfering light passes into a fiber-coupled single-shot spectrometer 12, which in this case is designed for the visually visible spectral range (VIS) and operates linearly in the wave number domain (k domain). A spectral wavelet sWL is recorded, which is shown in **detail 1.3**.

Figure 2 shows another exemplary interferometer with a Schwarzschild objective, which is configured as a dispersion-free single-shot point sensor with splitting of the wavefront. The optical set-up of this example is similar to the optical set-up of the example shown in Fig. 1 with the following differences: In this example the mirror surface formed in the central region of the primary mirror 6 of the Schwarzschild objective 5 is formed by a concave off-axis coupling mirror 81, which is used for coupling and decoupling reference light and for forming a focused reference beam bundle. The coupling mirror 81 is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5 and causes splitting of the input wavefront EWF. The decoupled reference bundle RB is inclined with respect to the optical axis of the Schwarzschild objective 5 and impinges on a miniaturized plane mirror 88. The plane mirror 88 is arranged outside the optical axis of the Schwarzschild objective 5 and serves as a reference end mirror. Due to the external location of the miniaturized plane mirror 88, the mounting can be made more compact and the input wavefront EWF is not affected by the plane mirror 88. **Detail 2.4** represents an enlarged view of the reference beam formed by the mirror 81 and the plane mirror 88. Due to the projection of the concave off-axis coupling mirror 81 from the surface of the primary mirror, the manufacture of its off-axis mirror surface is easily possible, for example by single-point diamond turning.

Figure 3 shows a partial view of a third example of an interferometer with a Schwarzschild objective configured as a single-shot point sensor. The optical set-up of this interferometer is similar to that of the interferometer shown in Fig. 2, with the following differences: The mirror surface formed in the central region of the primary mirror 6 is formed as a small plane coupling mirror 82, which can also be produced easily by single-point diamond turning and which is arranged centrally with respect to the convex primary mirror 6. A small triple mirror reflector 87 (hollow cube reflector), which renders the optical system insensitive to a moderate misalignment of the components, is used as the end reflector in the reference optical path. The reference light with a plane wavefront is reflected at the triple mirror reflector 87 and reaches the spectrometer 12 - as already described in figures 1 and 2 - where interference with the object light occurs.

Figure 4 shows a partial view of a fourth example of an interferometer with a Schwarzschild objective configured as a single-shot point sensor. In this example the primary convex mirror 6 of the Schwarzschild objective is provided with an opening 63, to which a small plane coupling mirror 83 is assigned, to which in turn a triple-mirror reflector 87 (hollow cube reflector) is assigned as a reference end reflector. The input wavefront is a plane wavefront, as in Figures 1 to 3.

Figure 5 shows a fifth example of an interferometer with a Schwarzschild objective configured as single-shot point sensor. The interferometer is configured as a classic spectral interferometer, in this case a Fizeau interferometer. The interferometer may be configured as a miniaturized variant of a Schwarzschild assembly in the visible spectral range so that the optical path difference xg remains below 1 mm. A comparatively high spectral resolution, which can be achieved with a long spectrometer line of, for example, 10.000 pixels, is required for an optical path difference xg of about 1 mm. Alternatively, the use of a frequency comb light source is also possible.

The Fizeau interferometer assembly comprises a transparent reference piece 61 having a curved shape in form of a meniscus. The meniscus shaped reference piece 61 is arranged below the primary mirror 6 of the Schwarzschild objective 6 (when viewed in the direction of propagation of the incoming light front). The meniscus shaped reference piece 61 may be connected to the Schwarzschild objective 5 and more specifically to the primary mirror 6 by a suitable connecting arrangement.

The incoming light front is reflected at the primary mirror 6 of the Schwarzschild objective 5 and after a reflection by the secondary mirror 9 of the Schwarzschild objective 5 impinges on the meniscus shaped reference piece 61. The meniscus shaped reference piece 61 has two curved surfaces, a first curved surface being arranged to face the secondary mirror of the Schwarzschild objective and a second curved surface 62 being opposite to the first curved surface. The curvature of the second curved surface 62 is higher than the curvature of the first curved surface.

After propagation through the first curved surface of the meniscus shaped reference piece 61 and the body of the meniscus, the light reaches the second curved surface 62. The light front impinging on the second curved surface ((Fizeau) splitter surface) is split into a reflected light front, which forms the reference light front or, respectively, the reference bundle and transmitted light front, which forms the object light front or, respective, the object light bundle. The second curved surface 62 at which a partial reflection takes place to thereby form a reference and an object beam thus serves as a Fizeau splitter surface.

One advantage of the above arrangement is that no “spider thread attachment” (spider) is necessary for the primary mirror and the Fizeau surface. The spider attachment of components in the prior art is comparatively susceptible to vibrations from the environment of the interferometer. By using a meniscus, i.e. a meniscus shaped reference piece, the assembly is unusually robust compared to the prior art, since the meniscus can be connected to the frame of a Schwarzschild objective with holders having a large material cross-section. With this arrangement, stable centering of the meniscus is possible by a high-stability frame, thereby ensuring long-term stability of the interferometer. It is further advantageous to apply an antireflection coating for particular spectral ranges or wavelengths on the meniscus, in order to avoid parasitic interferences.

The curvature of the second curved surface, i.e. of the Fizeau splitter surface, may at least partially correspond to the curvature of the wavefront impinging on the Fizeau splitter surface and forming a focus in the object space. Thus, it is possible to reduce the dispersions in the interferometric optical path.

The above approach is applicable from far infrared to ultraviolet, i.e. for all spectral regions for which there are available suitable transparent materials for the meniscus. Since suitable solid and at the same time transparent materials for the meniscus might not be available for the EUV range, this range may be excluded.

Figure 6 shows a sixth example of an interferometer with a Schwarzschild objective. The interferometer is a white light interferometer (short coherence interferometer) for a point, i.e. a time domain OCT system with splitting of the wavefront. The light comes from a fiber-coupled superluminescence light source block 101 with two SLDs. The spectrum of the superluminescence light source block 101 in the wavenumber domain (k domain) is symbolically described in **detail 6.1**. The white light interferogram (or short coherence interferogram) is recorded in the visible spectral range (VIS spectral range) by the fast photodiode 121. The white light interferogram (short-coherence interferogram), shown schematically in **detail 6.2**, is formed during focusing in different depth by a depth scan performed by a piezo scanner 131 moving the measurement object 10 in the depth.

In another example without a figure, a refractive collimator can be used, which is then advantageously implemented as an objective with a small chromatic longitudinal aberration.

Figure 7 shows a seventh example of an interferometer with a Schwarzschild objective. The interferometer is a scanning multi-point white light interferometer for a small field. A fiber-coupled superluminescence light source block with three SLDs in the VIS range is used for illumination, see also **detail 7.1**. A fiber bundle 104 with a total of 9 single-mode fibers terminating in a block 38 with 9 fiber ends is used. In this case, the collimator 41 is designed as a two-mirror system for better correction in the field. Splitting of the wavefront at the concave on-axis coupling mirror 8 takes place, as described in connection with Fig. 1. At the object 10, nine measurement points are simultaneously illuminated by means of a Schwarzschild objective 5. Depth scanning of the measurement object 10 is performed by means of a piezo scanner 131, which moves measured objects 10. After confocal discrimination at block 38, the interfering light reaches 9 photodiodes of a fast photodiode line 122 for the VIS range (VIS spectral range). Above the depth scan, 9 white light interferograms (or short coherence interferograms) are formed by the light detected by the 9 photodiodes. As an example, a white light interferogram, detected by means of a photodiode 122, is shown in

detail 7.2. In particular, detail 7.2 shows the detected intensity as a function of the optical path difference xg. The optical set-up of this example is otherwise similar to the optical set-up of the example shown in Fig. 1.

Figure 8 shows an eight example of an interferometer with a Schwarzschild objective. The interferometer of this example is configured as a dispersion-free interferometer system with splitting of the wavefront. The optical set-up of this example is similar to the one shown in Fig. 7 with the following differences: The interferometer comprises an EUV light source 106 for multi-point illumination (see **detail 8.1**). To this end, a pinhole array 391 is arranged downstream of the light source 106. Further, the interferometer comprises a two-stage collimating mirror system 41 arranged downstream of the pinhole array 391. The light points (formed by light passed through the pinholes of the pinhole array) are imaged onto the lithography mask 15 (i.e. the object to be measured) by the Schwarzschild objective 5 (in combination with the collimating mirror system 41) in a diffraction limited way, thereby forming a diffraction limited spots. The detector (image sensor 123) is an image sensor suitable for detecting electromagnetic radiation in the EUV spectral range, i.e. is an EUV-imaging detector. The interferometer is configured for measuring/testing a small field of the lithography mask 15 by using a phase shift method, utilizing a phase shift on a miniaturized plane mirror 86 in the reference arm. To enable phase shift, a piezo scanner (i.e. piezo phase shifter) 132 is arranged in the reference arm. The piezo scanner 132 moves the plane mirror 86 in a direction substantially parallel to the optical axis of the Schwarzschild objective 5, thereby introducing a phase shift.

Figure 9 shows a ninth example of an interferometer with a Schwarzschild objective. The interferometer of this example may be used for inspection of semiconductor lithography masks in the EUV range. The optical setup uses multi-point illumination and EUV-imaging detector. The inspection is performed using a phase-shift method. To minimize the scattering of the light, the mirror components may be formed of coated glass with super-polished surfaces, i.e. with super-smooth surfaces with a super-polishing. The interferometer comprises an EUV light source 106 and a pinhole array 391 arranged downstream of the light source 106 to enable multi-point illumination of the object to be measured (in this case lithography mask 15). The light points (formed by light passed through the pinholes) are imaged onto the lithography mask 15 by means of a Schwarzschild objective 5 in a diffraction limited way to form diffraction limited spots. The interferometer comprises further an image sensor (detector) 123 capable of detecting light in the EUV spectral range. The plane mirror 88 (reference end reflector) is arranged in the reference optical path/arm at a distance from the optical axis of the Schwarzschild objective 5, i.e. outside the optical axis of the Schwarzschild objective 5. The plane mirror 88 serves as a reference end mirror/reflector. Preferably, the plane mirror 88 is a super-polished glass mirror for minimizing scattered light. The mirror may be miniaturized and may for example have dimensions in the millimeter range, for example around 1 mm diameter. For phase shifting, a piezo scanner or piezo actuator132 that shifts the plane mirror 88 is arranged in the reference optical path/arm. Due to the EUV radiation and the numerical aperture of 0.5, a very high lateral resolution for the mask inspection can be achieved.

The Schwarzschild objective 5 comprises a convex primary mirror 64 and a secondary mirror 71, both made of glass and having super-polished reflecting surfaces. In a central part of the convex primary mirror there is provided an off-axis super-polished glass mirror 811 that is inserted into the convex primary mirror 64. As explained in connection with the preceding figures, the glass mirror 811 reflects a portion of the incoming light beam to form a reference beam propagating at angle to the optical axis of the Schwarzschild objective 5. **Detail 9.1** shows a section of the optical path with the off-axis glass mirror 811.

Further, the invention relates to the following aspects and examples:

Aspect 1: An interferometer with a Schwarzschild objective, in particular also for spectral interferometry for detecting distance, depth, profile, microprofile, shape, ripple and/or roughness of the optical path length in or on technical or biological objects, also in layer form, or also for optical coherence tomography (OCT), in each case in at least one point, but also for the inspection of masks of semiconductor lithography in the EUV range by means of the phase shifting method.

The interferometer comprises the following means/components:

> a source of electromagnetic radiation 1, 101, 102, 106 for illumination of the object 10, 15, said interferometer being designed with an object O and with at least one reference optical path R, in which at least one end reflector 86, 87, 88 is arranged, or a Fizeau splitter surface 62 is arranged in the optical path of a Fizeau interferometer, and at least

one measurement point MP in the object optical path, in which a surface or volume element of the object 10, 15 to be measured is at least approximately located,

as well as a Schwarzschild objective 5 with a concave primary mirror 6 with a center region, usually not used, for object illumination and a secondary mirror 7 for illuminating and imaging at least one single object point of the object (10, 15), and a detector 12, 121, 122, 123 for detecting electromagnetic radiation in the form of at least one interferogram intensity,

and at least one reference end reflector is arranged in the reference optical path R of the interferometer.

The interferometer is characterized in that

a mirror surface 8, 81, 811, 82, downstream of which is arranged the reference end reflector 8, 86, 87, 88, is formed in the center region of the concave primary mirror 6 of the Schwarzschild objective 5, which is usually optically not used in the prior art,

or a through-opening 63, to which a plane or concave mirror 83 below the primary mirror 6 - below in the standard representation of a Schwarzschild objective 5 - is assigned, is provided in the center region of the primary mirror 6, which is not used in the prior art, said reference end reflector 8, 86, 87, 88 being arranged downstream of said mirror 83 in the reference optical path,

or the Fizeau splitter surface 62 of a Fizeau interferometer is formed with a meniscus 61 having a curvature at least approximately corresponding to the curvature of the wavefront impinging on the Fizeau splitter surface (62) and forming a focus in the object space.

Aspect 2: The interferometer with a Schwarzschild objective according to aspect 1, wherein the mirror surface or the mirror 83 is plane or the mirror is formed to be concave behind the through-opening 63.

Aspect 3: The interferometer with a Schwarzschild objective according to at least one of the preceding aspects, wherein the mirror surface 8, 81, 82 or the mirror 83 is designed as an on-axis or off-axis surface with respect to the axis of symmetry of the Schwarzschild objective 5.

Aspect 4: The interferometer with a Schwarzschild objective according to aspect 2, wherein the concave mirror surface 8, 81 on the primary mirror 6 of the Schwarzschild objective 5 is formed with an on-axis or off-axis surface 92 with respect to the axis of symmetry of the Schwarzschild objective 5.

Aspect 5: The interferometer with a Schwarzschild objective according to any one of aspects 2 to 4, wherein the concave mirror surface 8, 81 is designed as a rotary paraboloid.

Aspect 6: The interferometer with a Schwarzschild objective according to aspect 1, wherein a mirror 83 or a mirror surface for deflecting the light to the reference end reflector 87 is arranged downstream of the of the through-opening of the primary mirror.

Aspect 7: The interferometer with a Schwarzschild objective according to any one of aspects 1 to 6, wherein the source of electromagnetic radiation 1 for illuminating the object 10, 101, 102 is designed to be spectrally broad-banded.

Aspect 8: The interferometer with a Schwarzschild objective according to one of aspects 1 to 6, wherein the source of electromagnetic radiation for illuminating the object 10, 15 is designed as an X-ray light source or EUV light source 106.

Aspect 9: The interferometer with a Schwarzschild objective according to one of aspects 1 to 8, wherein the interferometer is designed as a spectral interferometer and the source of electromagnetic radiation 1, 101, 102 is designed to be multispectral.

Aspect 10: The interferometer with a Schwarzschild objective according to one of aspects 1 to 8, wherein the interferometer is designed with a tunable light or radiation source.

Aspect 11: The interferometer with a Schwarzschild objective according to aspect 9, wherein a spectrometer 12 is arranged at the output of the interferometer.

Aspect 12: The interferometer with a Schwarzschild objective according to one of aspects 9 and 11, wherein the spectrometer 12 is designed as a single-shot system.

Aspect 13: The interferometer with a Schwarzschild objective according to one of aspects 1 to 7 and 9 to 12, wherein a light source with a frequency comb spectrum is used.

Aspect 14: The interferometer with a Schwarzschild objective according to one of aspects 1 to 7 and 9 to 13, wherein the light source with a frequency comb spectrum is designed as a frequency comb laser.

Aspect 15: The interferometer with a Schwarzschild objective according to one of aspects 1 to 14, wherein the interferometer is designed as a Michelson type, a Fizeau type, or a Mach-Zehnder type.

The computational aspects of the proposed method and assembly described above can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. When appropriate, aspects of these systems and techniques can be implemented in a computer program product, for example tangibly embodied in a machine-readable storage device for execution by a programmable processor; and method steps can be performed by a programmable processor executing a program of instructions to perform functions by operating on input data and generating an output. To provide for interaction with a user, a computer system can be used having a display device, such as a monitor or a LCD screen for displaying information to the user and a keyboard, a pointing device such as a mouse or a trackball, a touch-sensitive screen, or any other device by which the user may provide input to computer system. The computer system can be programmed to provide a graphical user interface through which the computer program(s) interact(s) with the user.

A number of embodiments and example have been described above. Nevertheless, it will be understood that various modifications may be made. For example, various components may be combined in a different manner and still achieve desirable results. Accordingly, other embodiments are within the scope of the claims.

Reference numeral list with explanations

Reference numeral	Designation
1	fiber-coupled superluminescence light source (SLD light source as an example of a source for electromagnetic radiation)
101	fiber-coupled superluminescence light source block (SLD light source block, here with 2 SLDs, as an example of a source for electromagnetic radiation)
102	fiber-coupled superluminescence light source block (SLD light source block, here with 3 SLDs, as an example of a source for electromagnetic radiation)
103	fiber bundle with a total of 9 single-mode fibers
104	Block with a total of 9 Y-switches for decoupling into the single-mode fibers
105	fiber bundle with a total of 9 single-mode fibers
106	EUV light source (as an example of a source for electromagnetic radiation)
2	single-mode fiber
3	output of the single-mode fiber
38	block with 9 fiber ends
39	pinhole array
391	pinhole array for EUV for diffraction limited imaging of the pinholes by the Schwarzschild objective
4	collimating mirror designed as a rotary paraboloid
41	two-stage collimating mirror system
5	Schwarzschild objective
6	convex primary mirror of the Schwarzschild objective
61	meniscus
62	Fizeau splitter surface on meniscus 61
63	opening in the convex primary mirror 6

64	convex primary mirror of the Schwarzschild objective made of glass
7	concave secondary mirror of the Schwarzschild objective
71	concave secondary mirror of the Schwarzschild objective made of glass
8	concave on-axis coupling mirror for coupling and decoupling reference light and forming a focused reference beam bundle RB. Mirror 8 causes splitting of the input wavefront EWF and is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5.
81	concave off-axis coupling mirror for coupling and decoupling reference light and forming a focused reference beam bundle. Mirror 81 causes splitting of the input wavefront EWF and is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5. The decoupled reference beam RB is inclined with respect to the optical axis of the Schwarzschild objective 5.
811	off-axis glass mirror that is inserted into the convex primary mirror 64 made of glass and is super-polished.
82	(small) planar coupling mirror, arranged centrally to the convex primary mirror 6. The decoupled reference beam RB is inclined with respect to the optical axis of the Schwarzschild objective 5.
83	(small) planar coupling mirror below the opening 63 in the convex primary mirror 6. Usually, it is a deflection mirror for coupling and decoupling the light. However, it is also possible that this mirror is an interferometer end mirror and thus also serves as a reference end mirror. This results in a strongly detuned interferometer, that is, the optical path difference xg is comparatively very large then.
86	miniaturized plane mirror, which is arranged coaxially with respect to the optical axis of the Schwarzschild objective 5 and serves as a reference end mirror.
87	triple mirror reflector (hollow cube reflector)
88	miniaturized plane mirror, which is arranged outside the optical axis of the Schwarzschild objective 5 and serves as a reference end mirror.
9	concave secondary mirror of the Schwarzschild objective
10	measurement object
11	Y switch
12	fiber-coupled single-shot spectrometer for the visible spectral range (VIS)
121	fast photo diode, VIS spectral range
122	fast photo diode row for the VIS range (VIS spectral range)

123	Image receiver for EUV light (extreme ultra violet imaging detector, 13nm wave length spectral range)
124	fast multi-point receiver for EUV light (fast rastered detector for extreme ultra violet radiation 13nm wave length spectral range)
131	piezo scanner for the focusing of the measurement object 10 or 15
132	piezo scanner for phase shifting in the reference arm
14	thin beam splitter for EUV radiation, (multilayer beam splitter for EUV)
15	Lithography mask (example of a measurement object)
EWF	input wavefront
F	focal point of collimating mirror 4 or the two-stage collimating mirror systems 41
OB	focused object bundle in the interferometer (with missing center)
RB	reference bundle in the interferometer
sWL	spectral wavelet
WLI	white light interferogram

Claims

1. An optical interferometer comprising:

a source of electromagnetic radiation (1, 101, 102, 106) for illumination of at least one measurement point or field (MP) of an object to be measured (10, 15);

an object optical path (O), in which the at least one measurement point (MP) is arranged;

a reference optical path (R),

a Schwarzschild objective (5) with a concave primary mirror (6) and at least one secondary mirror (7) for illuminating and imaging the at least one measurement point or field (MP),

a detector (12, 121, 122, 123) for detecting electromagnetic radiation in the form of at least one interferogram intensity,

wherein:

a mirror surface (8, 81, 811, 82) is formed in a center region of the concave primary mirror (6) of the Schwarzschild objective (5) and a reference end reflector (8, 86, 87, 88) is arranged downstream of the mirror surface (8, 81, 811, 82) in the reference optical path (R), or

a through opening (63) is formed in the center region of the primary mirror (6), and a mirror (83) is arranged downstream of the through opening (63) in the reference optical path (R), or

a reference piece (61) having a meniscus shape is arranged downstream of the primary mirror (6) of the Schwarzschild objective (5), wherein one of the surfaces of the reference piece (61) is at least one partially reflective surface (62) having a curvature at least approximately corresponding to the curvature of the wavefront impinging on the at least one partially reflective splitter surface (62).

2. The interferometer according to claim 1, wherein a mirror surface (8, 81, 811, 82) or a through opening is formed in a center region of the concave primary mirror (6) of the

Schwarzschild objective (5), and wherein the mirror surface (8, 81, 811, 82) formed in the center region of the primary mirror (6) or the mirror (83) arranged downstream of the through-opening (63) is plane or concave,

3. The interferometer according to any one of the preceding claims, wherein a mirror surface (8, 81, 811, 82) or a through opening is formed in a center region of the concave primary mirror (6) of the Schwarzschild objective (5), and wherein the mirror surface (8, 81) formed in the center region of the primary mirror (6) or the mirror (83) arranged downstream of the through-opening (63) is a rotary paraboloid surface.

4. The interferometer according to any one of the preceding claims, wherein a mirror surface (8, 81, 811, 82) or a through opening is formed in a center region of the concave primary mirror (6) of the Schwarzschild objective (5), and wherein the mirror surface (8, 81, 82) formed in the center region of the primary mirror (6) or the mirror (83) arranged downstream of the through-opening (63) is arranged on-axis or off-axis with respect to an axis of symmetry of the Schwarzschild objective (5).

5. The interferometer according to any one of the preceding claims, wherein a through opening (63) is formed in the center region of the primary mirror (6) and a mirror (83) is arranged downstream of the through opening (63) in the reference optical path (R), and wherein a reference end reflector (8, 86, 87, 88) is arranged downstream in the reference optical path of said mirror (83) arranged downstream of the through-opening (63).

6. The interferometer according to any one of the preceding claims,

wherein the source of electromagnetic radiation (1) for illuminating the object (10, 101, 102) is one or more of a spectrally broad-band source, a multispectral source, a tunable light source, and a light source with a frequency comb spectrum; and/or

wherein the source of electromagnetic radiation (1) for illuminating the object (10, 101, 102) is an X-ray light source or EUV light source (106);

7. The interferometer according to any one of the preceding claims, wherein the source of electromagnetic radiation (1) for illuminating the object (10, 101, 102) comprises a plurality of point light sources or point light spots.

8. The interferometer according to claim 7, further comprising a pinhole array (39, 391) for confocal discrimination of reference focal spots formed by the plurality of the point light sources or point light spots.

9. The interferometer according to any one of the preceding claims, wherein:

the interferometer is a spectral interferometer; and/or

the interferometer further comprises a spectrometer (12) arranged at the output of the interferometer.

10. The interferometer according to claim 9, wherein the spectrometer (12) is a single-shot spectrometer.

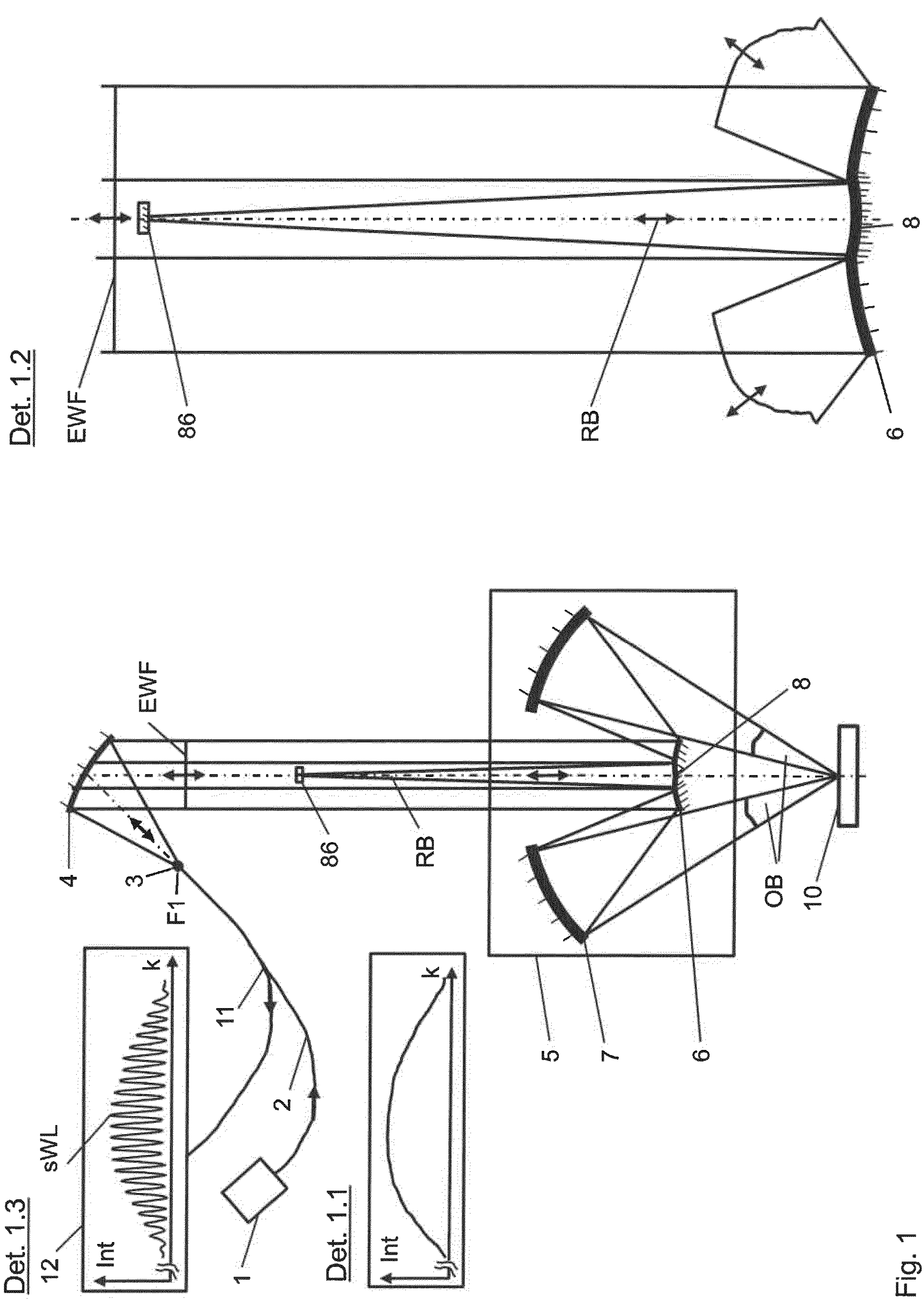
11. The interferometer according to one of the preceding claims, wherein the interferometer is a Michelson, a Fizeau, or a Mach-Zehnder interferometer.

12. A method for spectral interferometry or for spectral domain coherence tomography, comprising:

performing interferometric measurement or a spectral domain coherence tomography of an object to be measured by an optical interferometer according to any one of the preceding claims, and

obtaining at least one a measuring signal, said measuring signal including at least one spectral wavelet or at least one white light interferogram;

processing the measuring signal to obtain one or more of the following characteristics of the object to be measured: distance, depth, profile, microprofile, shape, ripple, roughness, optical path length, and optical coherence tomography data.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RB
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Det. 1.3
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Fig. 1

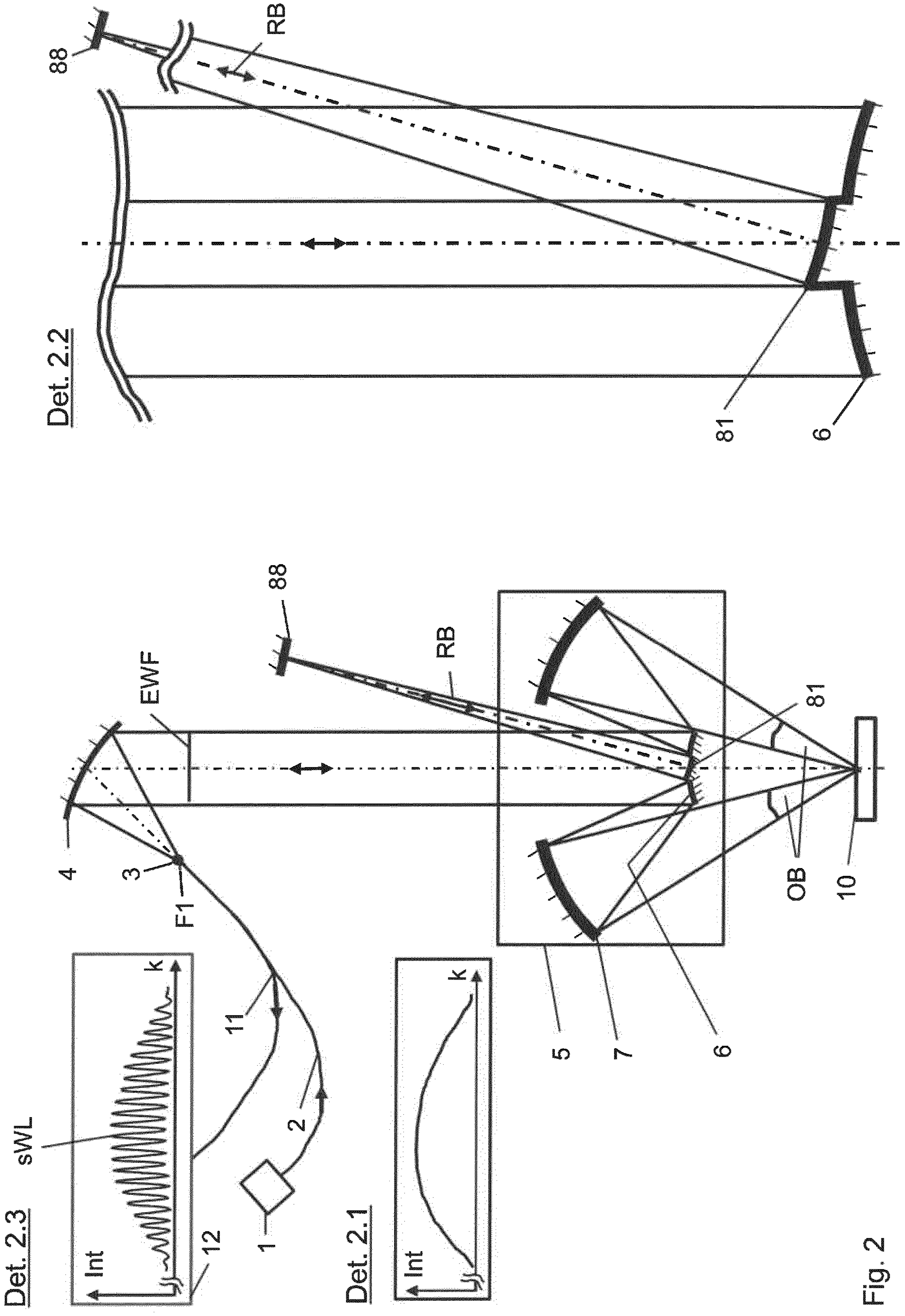
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Fig. 2

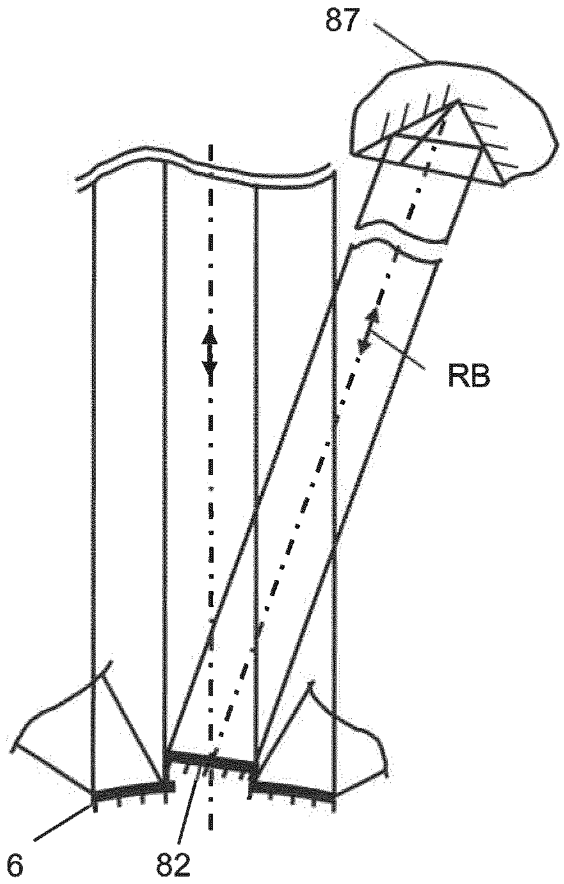

Fig. 3

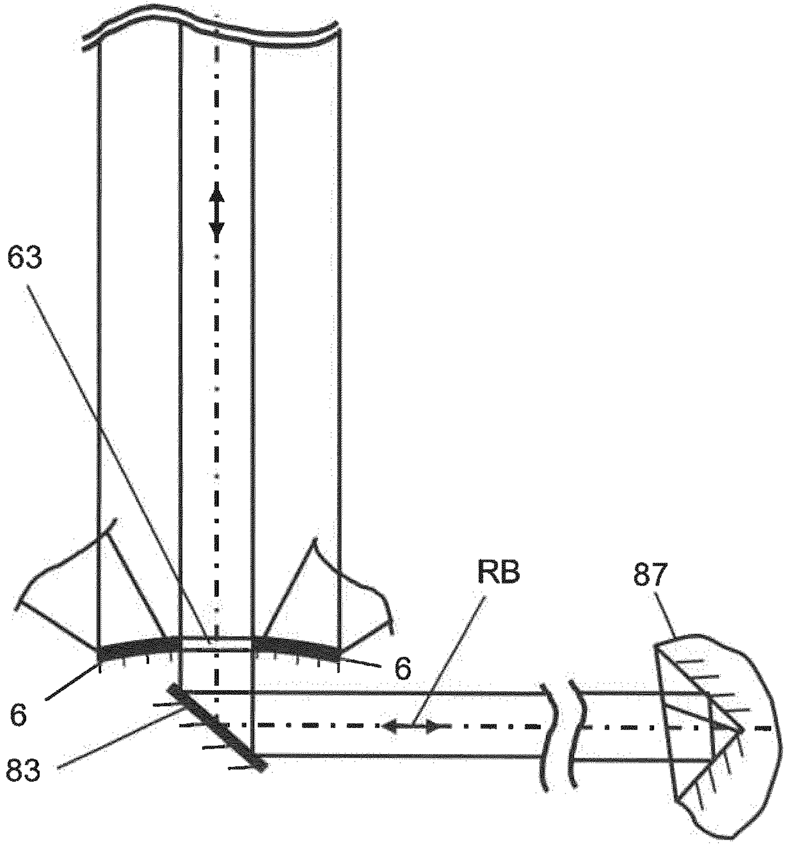

Fig. 4

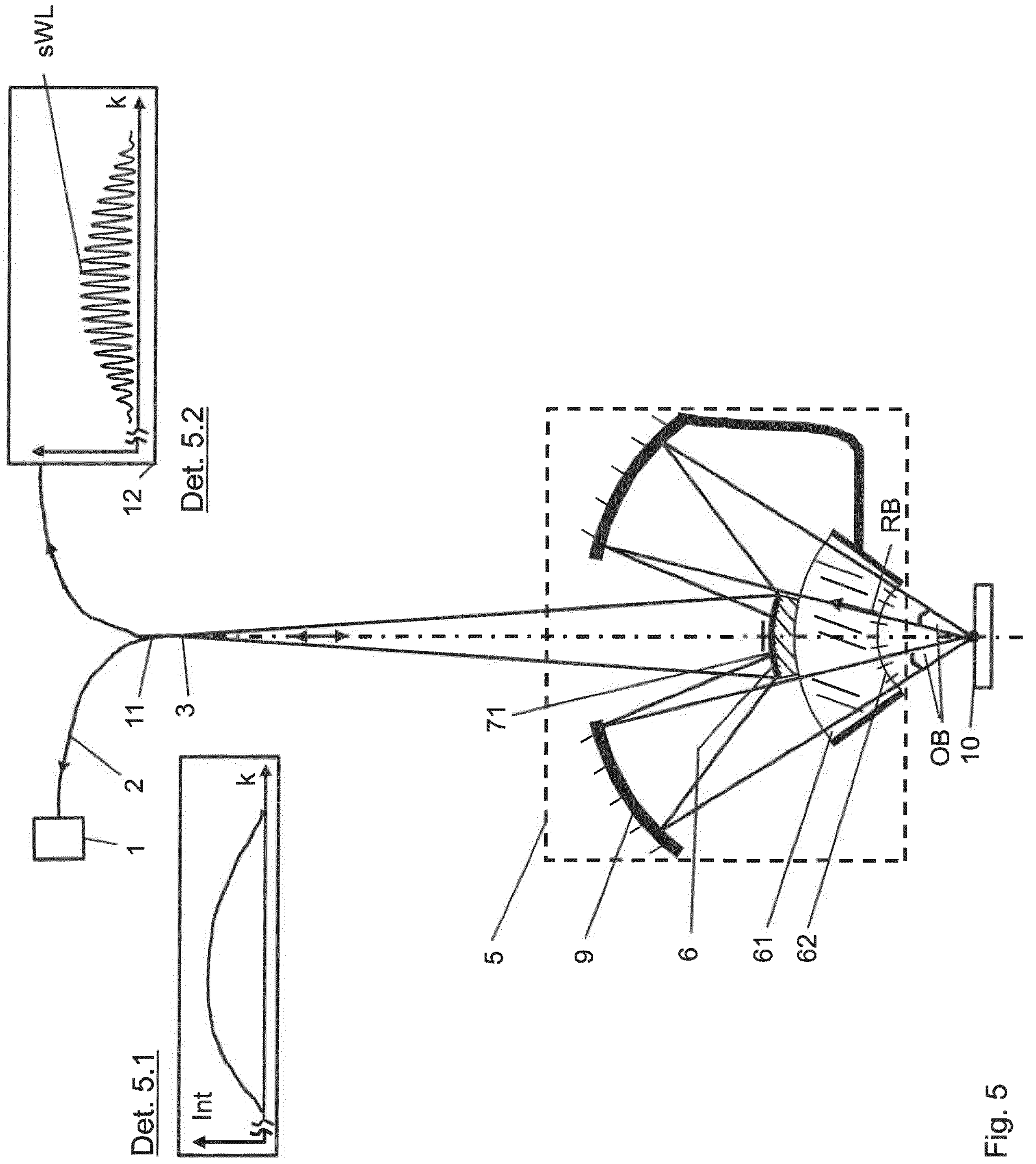

Fig. 5

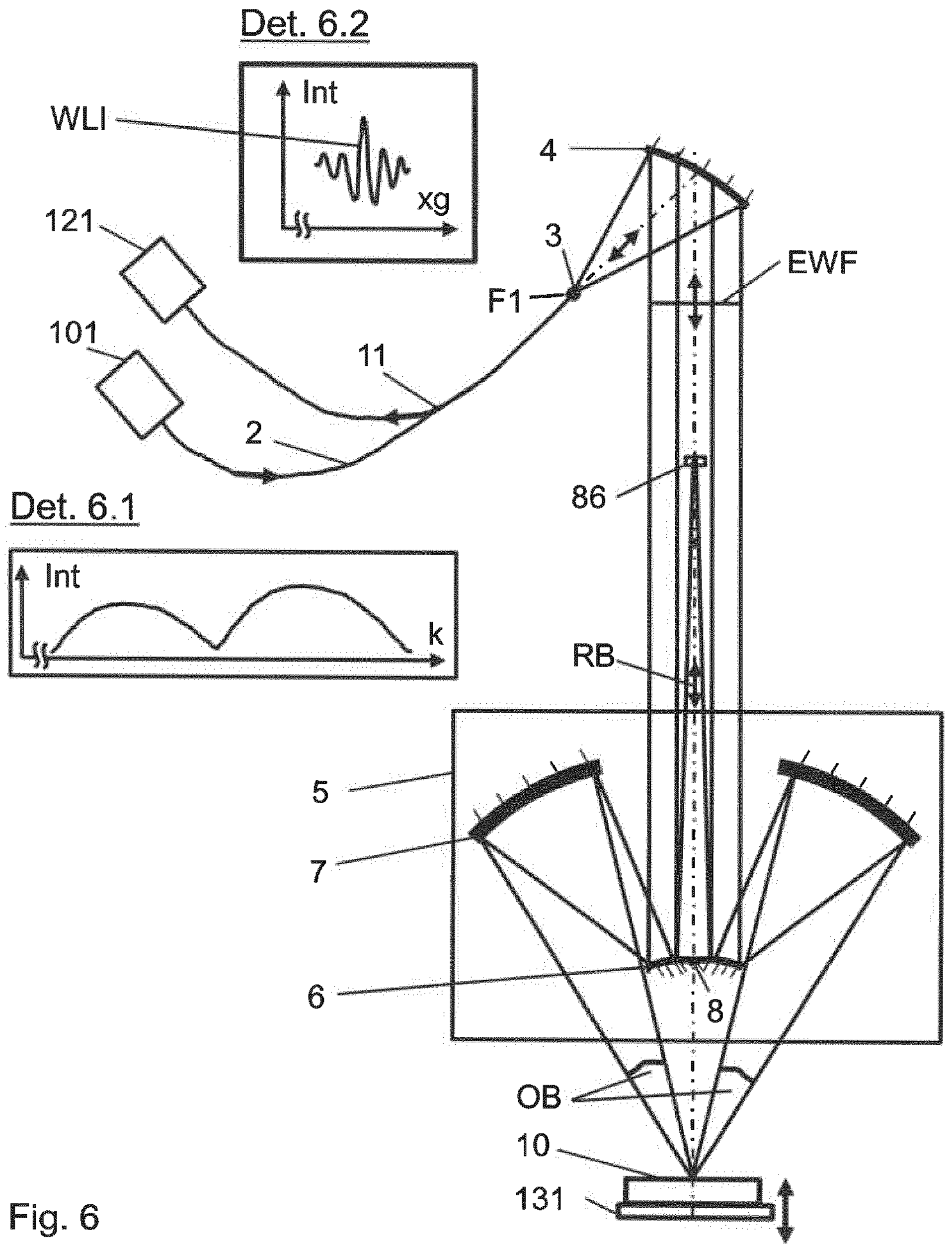
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Fig. 6

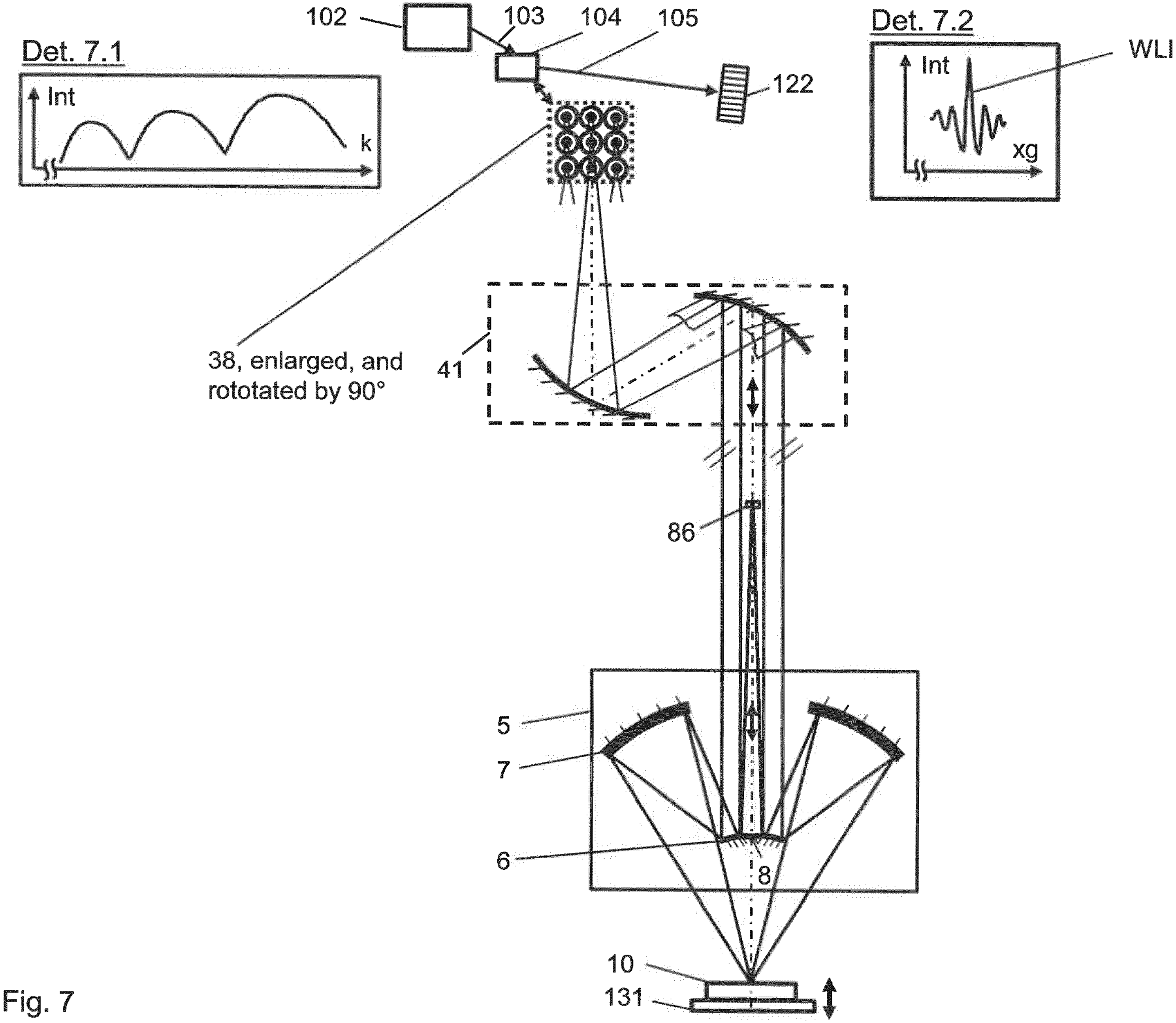
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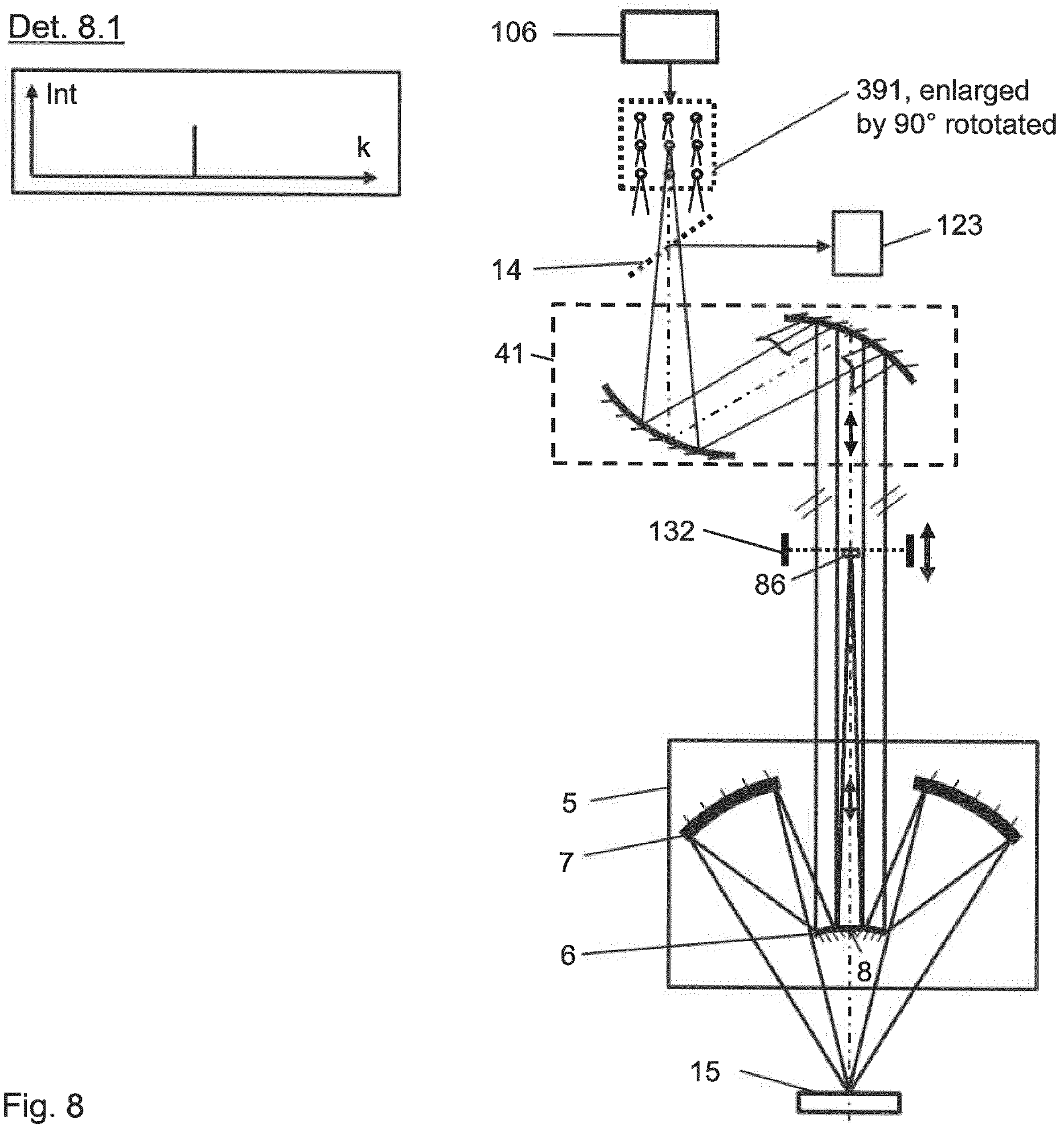
Fig. 7



Det. 8.1

Fig. 8

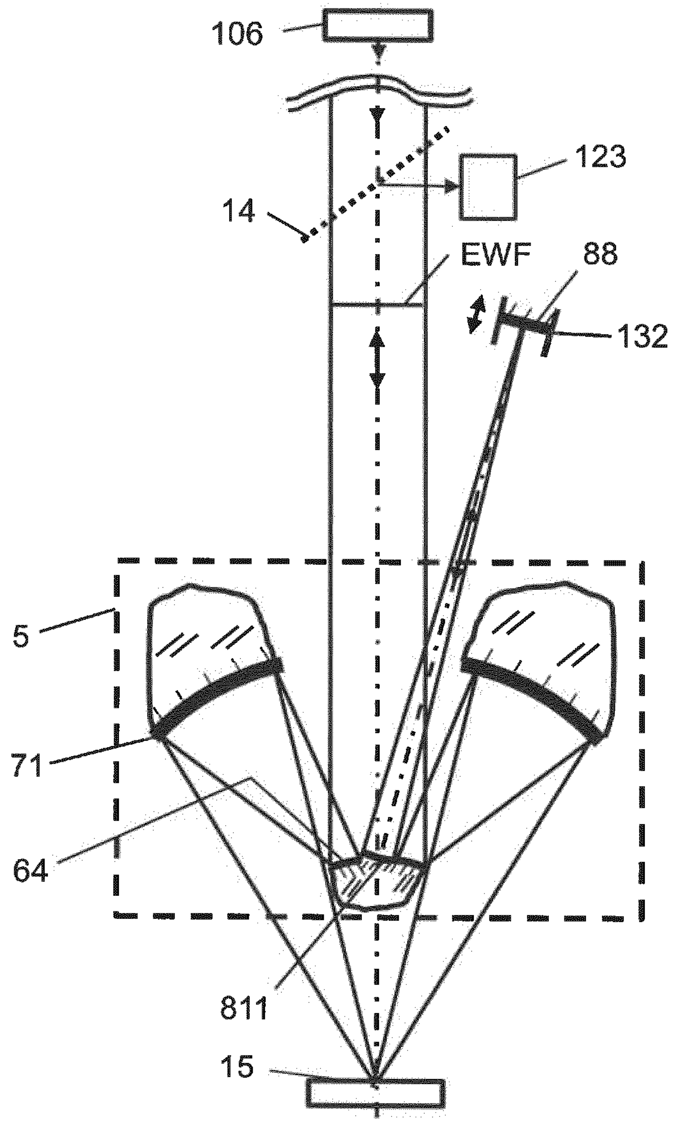
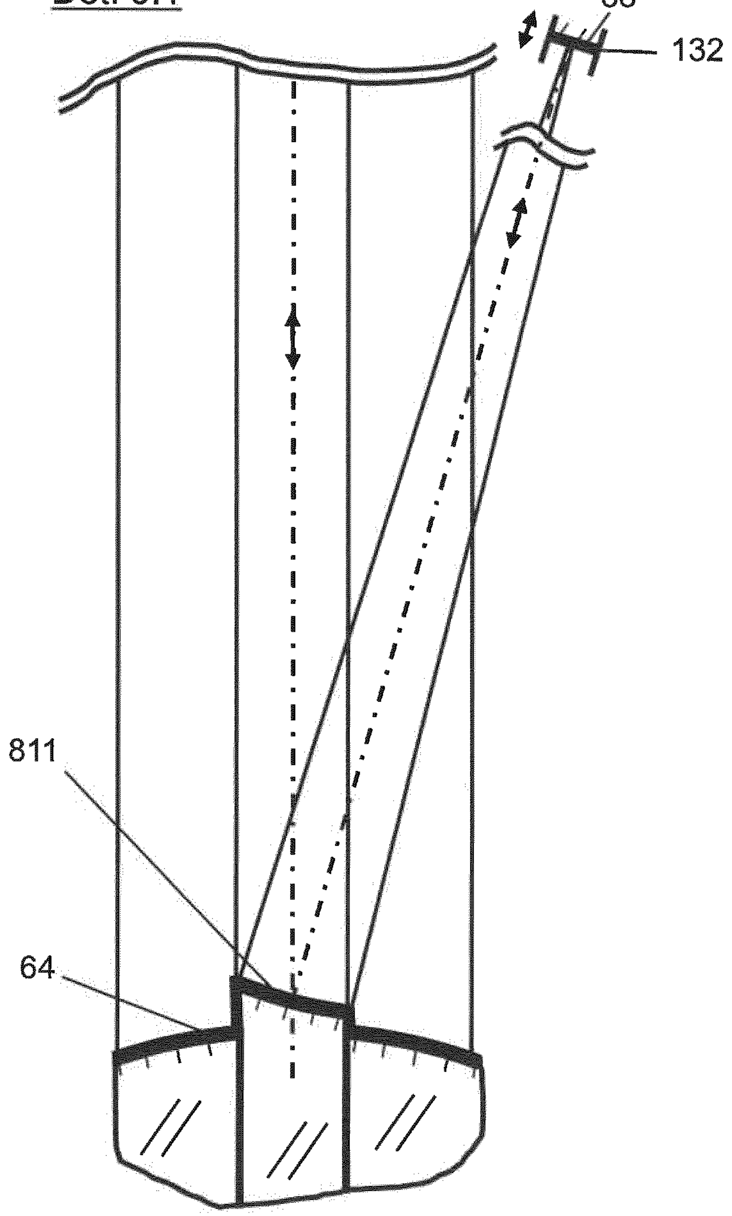


Fig. 9

Det. 9.1



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/083275

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B9/02 G01B11/24
ADD.

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

B. FIELDS SEARCHED

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

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	DE 10 2011 000213 A1 (UNIV KASSEL [DE]) 19 July 2012 (2012-07-19) paragraphs [0001], [0002], [0011], [0030] - [0037]; figure 2	1-6,11 7-10,12
X	HAGA TSUNEYUKI ET AL: "At-wavelength extreme ultraviolet lithography mask inspection using a Mirau interferometric microscope", JOURNAL OF VACUUM SCIENCE & TECHNOLOGY B: MICROELECTRONICSPROCESSING AND PHENOMENA, AMERICAN VACUUM SOCIETY, NEW YORK, NY, US, vol. 18, no. 6, 1 November 2000 (2000-11-01), pages 2916-2920, XP012008490, ISSN: 0734-211X, DOI: 10.1116/1.1319702 paragraph [II.A.]; figure 1	1-4,6

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☒ 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 27 April 2018	Date of mailing of the international search report 15/05/2018
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Fazio, Valentina

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EMER W ET AL: "ULTRAVIOLET INTERFEROMETRY WITH APOCHROMATIC REFLECTION OPTICS", APPLIED OPTICS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC; US, vol. 38, no. 16, 1 June 1999 (1999-06-01), pages 3516-3522, XP000835191, ISSN: 0003-6935, DOI: 10.1364/AO.38.003516 paragraph [002.]; figure 1 -----	1-4,6
Y	DE 10 2010 046907 A1 (UNIV STUTTGART [DE]) 16 February 2012 (2012-02-16) cited in the application the whole document -----	7-10,12
A	JP H11 211895 A (SHIMADZU CORP) 6 August 1999 (1999-08-06) paragraph [0005]; figure 1 -----	1

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2017/083275

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

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

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

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

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

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

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

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-12

An optical interferometer comprising: a source of electromagnetic radiation for illumination of at least one measurement point or field of an object to be measured; an object optical path, in which the at least one measurement point is arranged; a reference optical path, a Schwarzschild objective with a concave primary mirror and at least one secondary mirror for illuminating and imaging the at least one measurement point or field, a detector for detecting electromagnetic radiation in the form of at least one interferogram intensity, wherein: a through opening is formed in the center region of the primary mirror, and a mirror is arranged downstream of the through opening in the reference optical path.

1.1. claims: 1-4, 6-12

An optical interferometer comprising: a source of electromagnetic radiation for illumination of at least one measurement point or field of an object to be measured; an object optical path, in which the at least one measurement point is arranged; a reference optical path, a Schwarzschild objective with a concave primary mirror and at least one secondary mirror for illuminating and imaging the at least one measurement point or field, a detector for detecting electromagnetic radiation in the form of at least one interferogram intensity, wherein: a mirror surface is formed in a center region of the concave primary mirror of the Schwarzschild objective and a reference end reflector is arranged downstream of the mirror surface in the reference optical path.

1.2. claims: 1, 6-12

An optical interferometer comprising: a source of electromagnetic radiation for illumination of at least one measurement point or field of an object to be measured; an object optical path, in which the at least one measurement point is arranged; a reference optical path, a Schwarzschild objective with a concave primary mirror and at least one secondary mirror for illuminating and imaging the at least one measurement point or field, a detector for detecting electromagnetic radiation in the form of at least one interferogram intensity, wherein: a reference piece having a meniscus shape is arranged downstream of the primary mirror of the Schwarzschild objective, wherein one of the surfaces of the reference piece is at least one partially reflective surface having a curvature at least approximately corresponding to the curvature of the wavefront impinging on the at least one partially reflective splitter surface .

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/083275

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102011000213 A1	19-07-2012	NONE	
DE 102010046907 A1	16-02-2012	NONE	
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