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(71) Applicant *(for all designated States except US)*: **CARL ZEISS SMT AG** [DE/DE]; Carl-Zeiss-Str. 22, 73447 Oberkochen (DE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **SCHOLZ, Axel** [DE/DE]; Hofackerstrasse 43, 73430 Aalen (DE). **WEISS, Markus** [DE/DE]; Im Sonnenwinkel 9, 73430 Aalen (DE). **MAUL, Manfred** [DE/DE]; Elchweg 29, 73434 Aalen (DE). **BOSSELMANN, Philipp** [DE/DE]; Schwalbenweg 4, 73525 Schwäbisch Gmünd (DE).

(74) Agent: **SAWODNY, Michael**; Dreikönigg asse 10, 89073 Ulm (DE).

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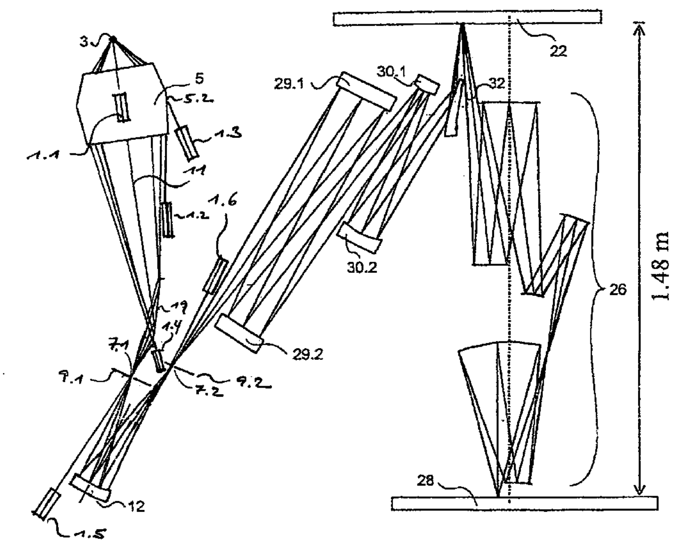
(54) **Title:** EUV ILLUMINATION SYSTEM WITH A SYSTEM FOR MEASURING FLUCTUATIONS OF THE LIGHT SOURCE



(57) **Abstract:** The invention relates to an EUV (extreme ultraviolet) illumination system with at least one EUV light source (3) ; with an aperture stop and sensor arrangement (1) for the measurement of intensity fluctuations and/or position changes of the EUV light source (3), in particular in the range of the effectively utilized wavelengths, or of one of the intermediate images of the EUV light source (3) , wherein the aperture stop and sensor arrangement (1) includes an aperture stop (2.1) and an EUV position sensor (2.3) ; wherein the aperture stop and sensor arrangement (1) is arranged in such a way that the aperture stop (2.1) allows a certain solid angle range of the radiation originating from the EUV light source (3) or from one of its intermediate images (7) to fall on the EUV position sensor.

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EUV ILLUMINATION SYSTEM WITH A SYSTEM FOR MEASURING FLUCTUATIONS OF THE LIGHT SOURCE

The invention relates to an EUV (extreme ultraviolet) illumination system with measurement means for determining and correcting the position of an EUV light source and the position of the focus of an optical collector system which follows in the light path in an illumination system with wavelengths ≤ 193 nm, in particular for applications in EUV lithography; and the invention also relates to a method serving the same purpose. The preferred measurement means to use in the illumination system is an aperture stop and sensor arrangement.

To allow a further reduction in the structure widths for electronic components, in particular into the sub-micron range, it is necessary to reduce the wavelength of the light used for the microlithography process. For example at wavelengths shorter than 193 nm, lithography with soft X-rays, so-called EUV lithography, offers a conceivable solution.

The wavelengths λ of 11 to 14 nm, with particular preference 13.5 nm, can be produced for example by a synchrotron source. However, using a synchrotron source has the disadvantage that it involves an apparatus of high technical complexity. Alternative EUV light sources are laser-plasma sources in which plasma is produced for example by focusing a laser beam onto a metal plate. Also used as EUV sources are plasma discharge sources where the plasma light source establishes itself in direct proximity to electrodes. In comparison to synchrotron sources, EUV plasma light sources are distinguished by significantly lower investment costs. As a drawback on the other hand, EUV plasma light sources are characterized by latent instability, and accordingly the source power fluctuates. Furthermore, because of thermal effects, the source point of the plasma source migrates.

As the emissions from the plasma are not limited to useful photons in the EUV range but also include light of longer wavelength as well as material particles of the metal plate or the electrode, the components which follow in the optical system, and in particular the collector unit and the first multilayered mirror, are subject to a high risk of contamination. Furthermore, the optical system of the collector is subject to deformation due to heat exposure and the effects of temperature gradients during operation, so that its focal length varies. Besides the migration of the source point of the plasma light source, the foregoing factors represent further causes for a non-uniform illumination of a field in the field plane of the illumination system. Furthermore, fluctuations of the telecentricity error as well as a strong fluctuation of the absorbed light power, a so-called dose error, can occur as a consequence.

EUV illumination systems with a plasma light source which, however, offer no solution for the foregoing problems are described in the following printed publications:

An EUV illumination system for a lithography apparatus which uses EUV radiation is disclosed in US 5,339,346. To achieve a uniform illumination in the reticle plane and to fill the pupil, an optical condenser is proposed in US 5,339,346, which is designed as a collector lens and includes at least four mirror facets set up in pairs which are arranged symmetrically.

An illumination system with a plasma light source is presented in US 5,737,137, which includes a condenser mirror, wherein a uniform illumination of a mask or reticle to be illuminated is achieved by means of spherical mirrors. This illumination system represents an illumination system with critical illumination.

The illumination system shown in US 5,361,292 is equipped with a plasma light source. As an image of the point-shaped light source, a condenser with an off-centered arrangement of five aspherical mirrors produces a ring-shaped illuminated area. With a special sequence of grazing-incidence mirrors following in the light path, the ring-shaped illuminated area is projected into the entry pupil.

Likewise, if synchrotron radiation is used as EUV light source, the field illumination will still be subject to a variation over both time and space due to the aforementioned thermal effects on the collector optics and on the immediately following reflective optical components. However, this effect is particularly pronounced in plasma light sources. In EUV illumination systems of this type it is therefore necessary to monitor the radiation that originates from the EUV light source and is collected by the subsequent reflective optical systems, and to adapt the position of the light source appropriately if there are deviations from the reference point. Alternatively, instead of adapting the light source itself, the position of an image of the light source can be adapted, for example by means of an optical component.

If EUV sensors with spatial resolution are used for monitoring the position, such as two-dimensional EUV photodiode arrays or sensors which measure the location-specific photo current or photo electrons, the following drawbacks are found which are due to the physical sizes of the sensors: For one, the sensors used for the measurement, block part of the light path, so that the usable illumination intensity is reduced commensurately. This drawback can only be overcome if the measuring system operates discontinuously and is moved out of the light path during the normal operation of the illumination system. However, this involves an expensive construction. Furthermore, difficulties occur in the adjustment. Also, a continuous adaptation by a servo-control of the source position of the EUV light source or an adaptation of the collector optics is not possible with this approach.

As a further problem associated with using the conventional two-dimensional sensors in the light path, the position of the source point of the light source can only be determined indirectly and thus inaccurately from the measurement of the intensity profile of a partial area of the illuminating light bundle.

In US 2003/0146391, a detector for monitoring the radiated light power of a plasma source is proposed which is located in a detector light path that is separate from the illumination light path. In this arrangement, the etendue (light-gathering power) of the detector light path is matched to the illumination light path in order to simulate the latter as accurately as possible. However, the concept proposed in US 2003/0146391 has the disadvantage that the measurement of the radiated light power in a separate light path is by itself not sufficient in order to assure that none of the errors named above will occur with their consequences on the image in the image plane, namely an inhomogeneously illuminated field, telecentricity errors as well as dose errors.

JP 63-072116 discloses the concept of determining secondary electrons which originate from an absorbent mask for the proximity exposure with X-ray light. However, this does not offer the possibilities of a measurement with spatial resolution, the determination of dose errors, or the determination of a contamination of optical components.

A method of monitoring the degree of contamination of a mirror for synchrotron radiation is disclosed in JP 05-288696. Under this method, the integral of the photo-voltaic current is determined over the mirror surface, so that no information is available on the spatial distribution of the radiation intensity.

The object of the invention is to overcome the drawbacks of the prior art. The aim is to propose in particular an EUV illumination system with a measurement means, wherein the measurement means is capable of determining with sufficient accuracy the location of the source position as well as the source power of an EUV light source, specifically of an EUV plasma light source, with this determination being made in regard to the effectively utilized wavelength. The part of the illumination intensity that is removed by the measurement means is to be kept as small as possible. The measurement means is further required to detect the change of the focus position of an optical collector system that is arranged downstream. A further object is to propose a method of monitoring an EUV light source, so that it becomes possible to adapt the position of an EUV light source as well as the adjustment of the collector optics in a suitable manner in order to achieve a uniform illumination of a field in the field plane. Furthermore, the measurement means and the correction method shall have the capability to measure the absolute flow of radiation in the effectively utilized range, i.e. at the effectively utilized wavelength, that is captured to be put to use in the EUV illumination system. The term "effectively utilized wavelength" in the present context means the wavelength which is used for producing an image, for example of a structured mask, onto a light-sensitive coating by means of a projection exposure apparatus. For example, an effectively utilized wavelength or the effectively utilized wavelength range for EUV lithography is in the area of 13.5 nm, without being limited to this value. Other effectively utilized wavelengths are likewise possible.

In contrast to an adjustment at the effectively utilized wavelength, US 6,727,980 describes an example where the adjustment of a EUV light source is made at a wavelength other than the wavelength used for the imaging process, for example with visible light.

The inventors have recognized that to solve the foregoing object of the invention, it is necessary to directly observe the EUV light source or one of its subsequent intermediate images. However, a sensor in immediate proximity of the source point cannot be realized because of the conditions that are present in that location. Furthermore, this would cause a strong reduction of the illumination intensity due to obscurations. Instead of this approach, the inventors have found that by means of an aperture stop and sensor arrangement functioning in accordance with the principle of a pinhole camera it is possible to produce an image of an EUV light source that allows a much simpler way of detecting a change of position. Alternatively or in addition, instead of observing the EUV light source itself, one or more intermediate images of the EUV light source can be observed. If the image of the EUV light source migrates out of a reference position, a direct conclusion can be drawn regarding the position change of the EUV light source itself. In addition, the source power of the EUV light source can be determined from the illumination intensity of the image. With the apparatus and the method according to the invention, the source power and/or source position of the EUV light source (which emits light in a broad-band spectrum of wavelengths) can be detected at the effectively utilized wavelength or the effectively utilized wavelength range that is used in a projection exposure apparatus.

In the state-of-the-art solution according to, e.g., US 6,727,980, it was expressly not the effectively utilized wavelength that was used for the adjustment. Rather, the light used was visible light emitted by the EUV light source, with wavelengths different from the effectively utilized wavelength.

In this context the term "aperture stop and sensor arrangement" is used with the meaning of a measuring arrangement that includes at least one aperture stop and one EUV position sensor. The aperture stop is positioned between the object to be observed, in this case an EUV light source or one of its intermediate images, and the position sensor, wherein the EUV position sensor for this application is sensitive to EUV-radiation. Due to the effect of the aperture stop, the radiation originating from an object point and falling on the position sensor is typically limited to a small solid angle. Thus, no focusing occurs. Instead, because of the necessarily finite aperture stop diameter, the light originating from each object point has as its image a circle of confusion in accordance with the laws of central perspective or central projection. If the object to be projected and the aperture stop opening and the ratio between the object distance and the design length of the camera are sufficiently small, then the projection will set a limit on the size of the circles of confusion, and according to the principle of the pinhole camera an image of the object is produced which has however a certain degree of unsharpness. According to the invention, for the observation of an EUV light source or one of its intermediate images with an aperture stop and sensor arrangement one uses for example EUV position sensors, so that no image in the actual sense is being taken. For this reason, the essential parameters of the aperture stop and sensor arrangement, i.e. object distance, aperture stop diameter, design length and sensor resolution, are selected according to the desired spatial resolution of the source point movement of the EUV light source and according to the object dimension, i.e., the selection deviates from the aforementioned condition.

As an extension of the inventive concept, two or more aperture stop and sensor arrangements are used which look at the light source from different angles of view. This allows the detection of a lateral as well as a longitudinal deviation from the reference position. If a collector is used which collects no light of the EUV light source below a minimal numerical aperture, it is possible to arrange at least one, but preferably at least two, aperture stop and sensor arrangements within this unused space. If this is not possible because of spatial constraints, one or several of the aperture stop sensor arrangements can be arranged in such a way that an unused partial ray is used to generate an image of the light source.

In the design of the passage openings through the collector optics or through components of a reflective optical system downstream of the collector, it is possible to position aperture stop and sensor arrangements in a rearward area that is normally obscured by the reflective optical surfaces.

The above also applies analogously to the observation of intermediate images by means of an aperture stop and sensor arrangement. In this regard, the inventors have found that the effects of position changes of the EUV light source and of changes in the collector optics manifest themselves in movements of intermediate images. Since this combination accounts for the actual amount of light taken in by the EUV illumination system, it is certainly possible based on an observation of the intermediate images to make an effective correction of the source point of the EUV light source or of the downstream collector optics or a part thereof.

It is particularly advantageous to observe the EUV light source as well as at least one of its intermediate images through aperture stop and sensor arrangements. This provides the possibility to separate the movement of the EUV light source from the changes of the focal length. It is further possible to distinguish fluctuations in the source intensity from, e.g., a contamination or degradation of the optical components that follow the EUV light source.

In addition to the aperture stop and sensor arrangements, the photo-electron current generated by the effect of the radiation can be measured with spatial resolution on at least one mirror. The sensor element used for this purpose includes an anode ring which, in turn, is composed of individual electrodes which share the same ground potential. By comparing the photo-electron currents in the electrodes it is possible to draw a conclusion about the gravity center of the radiation falling on the mirror surface. Furthermore, the sum of the photo-electron currents in the electrodes represents a measure for the total radiation intensity. The aforementioned sensor element can be used for the adjustment of the light ray pattern and likewise for determining the source point position as well as the focal lengths of optical elements that follow downstream in the light path. The preference in this is for a combined use wherein besides the sensor element, one additionally uses the aperture stop and sensor arrangements of the foregoing description.

The invention is hereinafter described through examples with references to the drawings, wherein:

Figure 1 shows two aperture stop and sensor arrangements which by observing the EUV light source and its intermediate image detect lateral and longitudinal deviations of the EUV light source from its reference position and changes of the focal length of the collector optics;

Figure 2 represents an EUV projection exposure apparatus with aperture stop and sensor arrangements for monitoring the EUV light source and its intermediate images;

Figure 3 illustrates the placement of an aperture stop and sensor arrangement along an optical axis in a nested collector;

Figure 4 illustrates the design structure of an aperture stop and sensor arrangement and the image projection of different source point positions;

Figure 5 illustrates the observation of the same EUV light source by means of two aperture stop and sensor arrangements inside the unused central space in a nested collector;

Figure 6 illustrates the placement of an aperture stop and sensor arrangement to the rear and following a collector shell;

Figure 7 illustrates the monitoring of an intermediate image of the EUV light source by means of two aperture stop and sensor arrangements;

Figure 8 illustrates how the axial measurement uncertainty of the position determination is estimated in the case of two crossed aperture stop and sensor arrangements;

Figure 9 shows an EUV position sensor functioning as quadrant detector;

Figure 10 illustrates the design structure of an aperture stop and sensor arrangement;

Figure 11 represents an assembly unit of two aperture stop and sensor arrangements as well as their placement within the unused space below a minimal aperture of a collector;

Figure 12 shows a sensor element for determining the photo current with spatial resolution on a reflective optical element; and

Figure 13 represents an alternative embodiment of a sensor element in accordance with Figure 12.

Figure 1 schematically illustrates an EUV light source 3 whose dimensions are small in comparison to the light-gathering optical collector 5.1. A light source 3 of this kind can be realized for example by the plasma produced as a result of shooting a laser beam at a metal plate. Alternatively, an EUV light emitting plasma of this kind is also produced in the vicinity of electrodes as a result of a discharge. In accordance with the coordinate system shown in Figure 1, the plane of the drawing contains the x- and y-axes. The EUV light source 3 is shown in a position 3.1 that is outside of its point of reference. As outlined in Figure 1, this position is observed by means of a first aperture stop and sensor arrangement 1.1 in particular at the effectively utilized wavelength. This aperture stop and sensor arrangement 1.1 is located at the center of the collector which is represented in a strongly simplified way by the outline of a collector shell 5.1. In regard to this type of a collector, the reader is referred to DE 101 38 284 A1, which was filed with the German Patent Office on behalf of the applicant and whose content in its entirety is incorporated by reference in the present application. The aperture stop and sensor arrangement is furthermore oriented along the optical axis 11 of the collector, which extends in the direction of the z-axis. In this arrangement, the first aperture stop and sensor arrangement 1.1 produces an image of the EUV light source 3 on a position detector 2.3.

A lateral movement of the EUV light source, i.e. a movement which produces a deviation from the reference position in the x-direction, or in the y-direction perpendicular to the plane of the drawing, translates into a deviation from the reference position of the image on the position detector 2.3 of the aperture stop and sensor arrangement 1.1, wherein in accordance with the laws of central perspective or central projection, the deviation conforms to the ratio of the lengths of Z_2 and Z_1 shown in Figure 1. By determining the deviation of the image on the position detector one can thus determine the deviation of the source position in the directions perpendicular to the axis which is defined by the reference position of the source and by the aperture stop center point of the aperture stop and sensor arrangement. The latter axis is in the present case the z-axis, and accordingly the sensor unit that is arranged in the center of the collector allows the determination of the source position relative to x and y.

The lengthwise deviation of the EUV light source from its reference position as well as the change of the focal length of the collector shell 5.1 is determined by means of the second aperture stop and sensor arrangement 1.2 which observes the intermediate image 7 of the EUV light source. Due to the orientation of the aperture stop and sensor arrangement at an angle β to the optical axis, it is possible to determine deviations of the intermediate image 7 from its reference position in the lateral and the longitudinal direction.

Different positions in which to install the aperture stop and sensor arrangements within the structure of an EUV projection system which is shown here as an example are illustrated schematically in Figure 2. Originating from an EUV light source 3, typically a plasma light source, light is gathered by way of a collector 5 which can for example be configured as a nested collector. A first aperture stop and sensor arrangement 1.1 is arranged in an unused space below a minimal aperture of the collector. This aperture stop and sensor arrangement can be positioned inside the collector or it can be designed as an assembly unit together with the latter. Preferably, a first aperture stop and sensor arrangement 1.1 is oriented along the optical axis of the collector.

If no optical axis can be defined in the collector 5, for example because the latter is of an asymmetric shape, one can subdivide the collector into individual segments and define a respective optical axis for each segment. A first aperture stop and sensor arrangement 1.1 which observes the EUV light source 3 directly can be placed along the mean of these axes. Furthermore, an aperture stop and sensor arrangement 1.1 near the EUV light source 3 can also be configured in such a way that it serves at the same time for the required central obscuration.

Beyond these possibilities, the afore-described measurement means according to the invention as well as the measurement and correction method can also be used for the monitoring and correction of a plurality of EUV light sources whose light is directed into the same EUV illumination system.

Figure 2 shows further aperture stop and sensor arrangements 1.2 and 1.3 which are positioned in the direction of a ray that is reflected at least once on the collector optics. In the illustrated arrangement, the aperture stop and sensor arrangement 1.2 follows the reflector optics, while the aperture stop and sensor arrangement 1.3 observes the EUV light source 3 through an opening 5.2 in the collector shell. Thus, the aperture stop and sensor arrangement 1.3 occupies a position on the rearward side of the collector. It is further possible to place an aperture stop and sensor arrangement 1.4 to the side of further optical elements such as a spectral grid filter 19. It is further possible to have an aperture stop and sensor arrangement 1.5 observing a first intermediate image 7.1. Analogously, further intermediate images, for example a second intermediate image 7.2, can be observed by means of a further aperture stop and sensor arrangement 1.6.

The possible embodiment of an EUV projection system that is illustrated in Figure contains as a further component an optical system that serves to form and illuminate the field plane 22 with a ring-shaped field. Configured as a mixing unit for the homogenous lighting of the field, the optical system is composed of two facet mirrors 29.1, 29.2 as well as two imaging mirrors 30.1, 30.2 and a field-forming grazing-incidence mirror 32.

The first facet mirror 29.1, the so-called field facet mirror, produces a multitude of secondary light sources in or near the plane of the second facet mirror 29.2, the so-called pupil facet mirror. The subsequent imaging optics form an image of the pupil facet mirror 29.2 in the exit pupil of the illumination system, which exit pupil is located in the entry pupil of the projection objective 26. The individual facets of the first and second facet mirrors, 29.1, 29.2 are inclined at such angles that the images of the individual field facets of the first facet mirror 29.1 overlap in the field plane 22 of the illumination system, so that it is possible to achieve a largely homogenized illumination of the structure-carrying mask located in said field plane 22. The segment of the ring field is given its shape by the field-forming grazing-incidence mirror 32.

A doubly faceted illumination system is disclosed for example in US Patent 6,198,793 B, and imaging and field-forming components are disclosed in WO 01/09681 which was filed at the US Patent Office under the application number US 10/060,909. The disclosure content of these documents in its entirety is incorporated herein by reference.

An image of the structure-carrying mask, also referred to as reticle, which is arranged in the field plane 22 is projected by means of a projection objective 26 into the image plane 28 of the field plane 22. The projection objective 26 is a 6-mirror projection objective as disclosed for example in the US patent application with serial number 60/255214 which was filed on December 13, 2000 at the US Patent Office on behalf of the applicant, also disclosed in the German patent application DE 10037870 A, the disclosure content of which in its entirety is incorporated by reference in the present application. The object to be exposed, for example a wafer, is arranged in the image plane 28.

Figure 3 shows an axial section through a nested collector with collector shells 5.1, three of which are shown as an example. Alternative embodiments of the collectors which include hyperboloid- and/or ellipsoid-shaped mirrors are described in the literature under the name of Wolter systems. Concerning the subject of Wolter systems, the reader is referred to *Wolter, Annalen der Physik 10, 94-114, 1952*, the disclosure content of which is incorporated herein by reference in its entirety. In collectors of this kind, light which originates from a substantially point-shaped light source is collected only above a certain minimal numerical aperture. Thus it is possible without a loss of light to position a measuring system according to the invention, which includes an aperture stop and sensor arrangement 1, in the unused space within the solid-angle that is below this minimal numerical aperture.

The imaging principle of an aperture stop and sensor arrangement is illustrated in Figure 4. The aperture stop and sensor arrangement itself is identified here by the reference symbol 1. If the aperture stop opening is so small that in an idealized view it could be considered as point-shaped, an image 4 of an object such as in this case the light source 3 is formed in any plane that extends substantially perpendicular to the axis of the imaging ray bundle. The scale of enlargement can be set by adjusting the ratio of the interval Z_1 from the aperture stop and sensor arrangement to the object in relation to the design length Z_2 which is defined as the distance between the aperture stop 2.1 and the image plane.

Figure 4 further shows the EUV light source in two positions 3.1, 3.2 that are out of the reference position. Since both of the positions 3.1, 3.2 lie on the same ray, they produce images whose center points coincide with each other. This shows that an aperture stop and sensor arrangement is suitable in essence for the determination of lateral deviations of the position of the EUV light source relative to the coordinate system of the aperture stop and sensor arrangement. In the case of a light source with finite dimensions, a longitudinal displacement will result in a change in the magnitude of the image in the aperture stop and sensor arrangement. In one embodiment, an EUV position sensor is used which has a sufficiently accurate spatial resolution to detect this kind of a change in magnitude. However, the preference is for an embodiment in which at least two aperture stop and sensor arrangements observe an EUV light source or, analogously, one of its intermediate images from different viewing directions.

In a real aperture stop opening of finite dimensions, the source image on the detector corresponding to the aperture stop area projected into the detector surface becomes blurred. However, the blurring is symmetric so that it causes no reduction, or only a negligible reduction, of the measuring accuracy, because the position of the gravity center of the substantially symmetrical source image remains unaffected by the blurring with a symmetrical aperture stop function.

In regard to the aperture stop opening, a compromise has to be found between the amount of power transmitted and the size of the detector. On the one hand, the aperture stop opening has to be selected small enough so as not to overexpose the sensor and thereby drive the sensor into saturation. On the other hand, one has to select the aperture stop opening for the determination of the position of the EUV light source large enough to provide a sufficient light intensity for the EUV position sensor. This is required in particular for the rapid determination of deviations in the position of the EUV light source.

If one further assumes a typical value of 150 mm for the object distance as well as an easy-to-realize resolution of 0.1 mm on the EUV position sensor, one can advantageously select a design length $Z_2 \geq 90$ mm.

An aperture stop and sensor arrangement that is used for the determination of the source position of an EUV light source includes a position detector 2.3. The latter serves to determine the amount by which the image of the EUV light source moves away from the reference image position. In the simplest case, an individual sensor element based on a photo diode is used for this purpose. In essence, however, this provides only one binary bit of information, i.e., whether or not the deviation of the EUV light source from its reference position is so small that the image is still within the sensor field. More information is delivered by a sensor that is composed of a plurality of photodiodes which are arranged in a row or preferably in the form of a matrix, and with particular preference in the form of a quadrant detector. The deviation of the position of the light source can be determined from the relative magnitudes of the signals of the individual sensor fields. An example of this type of a quadrant detector 44 is shown in Figure 9 with an x/y-coordinate system indicated for reference. From the respective intensity signals of the individual sensor fields A, B, C and D, the lateral deviations in the sensor plane are obtained as

$\Delta X' = [(B+D) - (A+C)]/(A+B+C+D)$ and

$\Delta Y' = [(A+B) - (C+D)]/(A+B+C+D)$.

From the summation taken over all of the sensor fields it is possible, after a calibration, to determine the total amount of power radiated from the light source, which is of particular importance for plasma light sources in which fluctuations of the source power can occur.

As the aperture stop and sensor arrangement according to the invention is used for the determination of position changes of the EUV light source or one of its intermediate images it is, in contrast to a classical pinhole camera, not necessary to take an actual image, and therefore no sensor combination with a fluorescent screen and camera is required, but only an EUV position sensor with a limited number of sensor elements. Particularly preferred is a quadrant detector. However, an image sensor represents a possible alternative as a sensor. It is further possible to configure the EUV position sensor 2.3 in such a way that the gravity center of the incident EUV radiation is determined from the emitted photo-electrons or from the photo current.

Since the installation space and thus the magnitude of the aperture stop and sensor arrangement that can be used is limited, it is necessary to position the latter in sufficiently close proximity to the light source that is to be observed. Thus, the ratio of Z_1 to Z_2 has to be made small enough. However, when getting closer to the light source, there is the risk of contamination by debris which results from the plasma generation. For this reason, a preferred measure is to place a particle filter 2.4 either before or after an aperture stop and sensor arrangement. As a further preferred feature, a spectral filter element 2.2 which limits the radiation of the EUV light source being investigated substantially to the effectively utilized range of wavelengths is placed in the radiation path before or after the aperture opening 2.1. This allows in particular radiation of the infrared, visible and EUV ranges to be held back. To perform this task, a foil filter can be used which contains for example zirconium. The latter will serve at the same time as a particle filter. As a further possibility, as shown in Figure 10, electromagnetic forces can be used for the deflection of charged particles, for example by arranging one or more pairs of magnetic poles 48 behind the aperture stop opening. In addition or as an alternative, multi-layered mirrors or spectral grid filters can be incorporated as additional elements in the aperture stop and sensor arrangement.

Figure 10 illustrates in a strongly simplified manner an aperture stop and sensor arrangement for determining the position of an EUV light source 3. The areas surrounding the aperture stop opening 2.1 are exposed to a strong heat inflow 40 due to the incident radiation. In an advantageous configuration of the aperture stop and sensor arrangement, the enclosure, being equipped with a cooling device 50 at its backside, for example a Peltier element or a liquid-coolant arrangement, is used to conduct the heat away. Due to the arrangement of the cooling device behind the sensor element, no additional obscuration effects occur in the illumination system. Furthermore, a preamplifier 52 can be advantageously placed in the closest possible proximity of the EUV position sensor 44 and provided with cooling. The remainder of the signal-evaluation electronics 54 can be placed outside of the aperture stop and sensor arrangement.

Figure 5 shows a corresponding arrangement of aperture stop and sensor arrangements, wherein a first aperture stop and sensor arrangement 1.1 is arranged along the optical axis of a nested collector, and a second aperture stop and sensor arrangement 1.2 is positioned in such a way that it observes the reference position of the EUV light source under an angle β to the optical axis and is otherwise arranged in the x/y plane of the drawing. In accordance with its orientation, the aperture stop and sensor arrangement 1.2 defines a local coordinate system g-h-k. Figure 5 shows the g- and k-axis, while the h-axis points out of the plane of the drawing. If the EUV light source is displaced to the position 3.1 which is out of the reference position by an amount Δx in the lateral direction and by Δz in the longitudinal direction in the x-y-z coordinate system, the following displacement components Δg, Δh, k of the image in the aperture stop and sensor arrangement are obtained through a coordinate transformation:

$$\Delta g = \Delta x \cos(\beta) - \Delta z \sin(\beta),$$
$$\Delta h = \Delta y,$$
$$\Delta k = \Delta x \sin(\beta) + \Delta z \cos(\beta).$$

As an alternative it is also possible that both aperture stop and sensor arrangement are positioned at an angle to the optical axis or that further aperture stop and sensor arrangements are added for monitoring the position of the EUV light source.

To arrive at an estimate for the measurement uncertainty Δz_a of the axial position, we consider in the following an aperture stop and sensor arrangement 1 oriented along the optical axis in combination with a second aperture stop and sensor arrangement directed transversely at an angle β to the optical axis. As indicated in Figure 8, the lateral measurement uncertainties Δx_{a1} and Δx_{a2} drawn in broken lines for the two aperture stop and sensor arrangements cross through each other. This shows that the measurement uncertainty Δz_a of the axial position can be calculated as follows:

$$\Delta z_a = \frac{\Delta x_{a1}}{\tan\beta} + \frac{\Delta x_{a2}}{\sin\beta}$$

Assuming an angle β of 10° and equal lateral measurement uncertainties $\Delta x_{a1} = \Delta x_{a2} = 0.58$ mm for the two aperture stop and sensor arrangements, one obtains from these numbers the result for a measurement uncertainty $\Delta z_a = 6.63$ mm of the axial position. As expected, at small angles β the axial uncertainty of the position measurement is significantly worse than the lateral uncertainty. The above mentioned values are only an example and should not be understood as an restriction.

Figure 6 shows alternative placements of the aperture stop and sensor arrangements to the rear of the collector optics or following after the latter. The terminology "placement to the rear of the collector optics" means that an aperture stop and sensor arrangement 1.1 is arranged in such a way that the latter observes the EUV light source through an opening in the collector mirror system. In an advantageous embodiment, this passage opening is designed as an aperture stop opening. The aperture stop and sensor arrangement is in this case seated directly on this aperture stop opening or designed to form an assembly unit with the aperture stop opening. This design configuration has the advantage that the loss of scattered light is minimized and that no individual adjustment of the aperture stop and sensor arrangement is necessary, due to the fact that the latter is coupled to a collector shell 5.1.

However, attention should be given to the fact that the collector shell 5.1, too, is subjected to a change of its position and length due to thermal effects. In one possible embodiment of the invention, the position changes of the collector shells 5.1 which lead to a displacement of the focal point, are determined by means of an additional measurement system, for example an interferometer. In an alternative embodiment, this function is likewise performed by an aperture stop and sensor arrangement 1.2 which is aligned to a ray that is reflected at least once at a reflector shell 5.1. The deviation of the image of this aperture stop and sensor arrangement 1.2 from the reference position thus contains the information concerning both the movement of the EUV light source as well as the changes in the geometry of the collector shell 5.1. Now, if one uses aperture stop and sensor arrangements that observe the EUV light source directly as well as aperture stop and sensor arrangements of the type in which at least one reflection at a collector shell 5.1 takes place, it is possible to separate these two different pieces of information from each other.

Alternatively or in addition, further aperture stop and sensor arrangements can be used which observe an intermediate image 7 of the EUV light source. As illustrated in Figure 7, unused partial ray bundles are used for this purpose, and the aperture stop and sensor arrangements are accordingly arranged in such a way that the spatial movement of the intermediate image can be captured. With a displacement of the source point of the EUV light source by Δx, Δy and Δz from the reference position one obtains in the intermediate image 7 for a marginal ray at the ray angle α the following conjugate values of the displacement components $\Delta x'$, $\Delta y'$ and $\Delta z'$ in the intermediate focus 7:

$$\sin(\alpha') = \sin(\alpha)/\beta,$$
$$\Delta x' = \Delta x * \beta,$$
$$\Delta y' = \Delta y * \beta,$$
$$\Delta z' = \Delta z * \beta^2.$$

These deviations of the intermediate image are again transformed into deviations in the corresponding coordinate systems of the aperture stop and sensor arrangements in accordance with their orientation relative to the reference point of the intermediate image.

Further possibilities include placing aperture stop and sensor arrangements at more than one intermediate image as well as using an arrangement of aperture stop and sensor arrangements where at least one aperture stop and sensor arrangement observes one of the intermediate images and at least one aperture stop and sensor arrangement observes the EUV light source directly.

The inventors have further found that for the measurement of the light originating from the light source, the mirror surface of one or more of reflective optical elements of the illumination system can be used as a sensor element. Under this concept, through the arrangement of electrodes above the mirror surface one can conclude backwards where the photo electrons originated from, with the electrons, in turn, being dependent on the local illumination intensity. From the profile of the illumination falling on a mirror surface, one can thus determine the ray position and based on it perform an adjustment without incurring the problem that the components used for the measurement protrude into the ray path and cause an obscuration. In addition the measurement of the total flow of photo electrons allows a conclusion about the strength of the radiation.

Figure 12 illustrates a possible arrangement of electrodes 36 for the measurement of photo electrons which originate from a mirror surface 38. In this representation, an anode ring 34 is outlined which is subdivided into four independent ring segments, where each of the electrodes, which are separate and electrically insulated from each other, is at the same electrical potential. Although it is possible to set a voltage potential at the electrodes 36, this is not an absolute requirement for the measurement of a photo current, because due to the photoelectric effect a difference in the electrical potential builds itself up between the irradiated mirror surface 38 and the anode ring 34. Based on the measurement of the respective photo currents of the electrodes, the gravity center of the origination of photo electrons is determined from the ratio of the measured currents I_1 to I_4. The sum of the measured currents I_1 to I_4 represents a measure for the strength of the radiation falling on the mirror.

The detail design of the electrodes 36 of the anode ring 34 is a matter of professional choice. Preferred, however, is a design where an obscuration of the ray path by the electrodes is avoided. In addition, it is also possible to vary the distance from the anode ring 34 to the mirror surface 38, with a distance of a small number of centimeters being preferred. Instead of the subdivision of the anode ring 34 into four electrodes 36 which cover a rectangular area above the mirror, it is also possible to configure an anode ring 34 in the shape of a triangle of three electrodes 36. Further, in a simplified version, one could use only two electrodes 36 instead of an anode ring 34 and thus determine the intensity profile of the mirror for one direction. In a further embodiment, the anode ring 34 can be made up of more than four electrodes 36, so that the anode ring 34 approaches the form a circle. Furthermore, this allows the shape to be adapted to the outside contour of the illuminated surface on the mirror. In a further embodiment, a plurality of anode rings are used instead of a single anode ring 34 to receive the photo current. The anode rings can be arranged for example concentrically, or they can have different distances from the mirror surface 38. In this way, the origin of the photo electrons can be determined with better spatial resolution.

The sensor element of the foregoing description can be used to draw conclusions about the source point of the EUV light source by examining the profile of the illumination falling on the mirror. To accomplish his, a single sensor element can be used or, if a plurality of mirrors are equipped with sensor elements, one can use a system of sensor elements.

In an alternative embodiment of the sensor element, the photo current is measured on individual facets of a facet mirror 29.1 that is arranged in the ray path. According to Figure 13, the facets 39.2 that are selected for the measurement of the photo current are electrically insulated from each other as well as from the rest of the facets, and each is equipped with an ampere meter 53. By comparing the individual photo currents to each other, it is possible to make a relative statement about the spatial distribution of the strength of the illumination that falls on the facet mirror 29.1. With this concept, it is preferred to equip as many facets as possible with photo current measurement devices, in order to achieve a sufficiently accurate spatial resolution in the measurement. However, for practical reasons, there can also be facet elements 39.1 without an electrical connection for the determination of the photo current. In particular, this is possible if the elements that have such a connection are arranged in a structured order on the facet mirror. If a calibration of the photo current measurement is performed at a known strength of the radiation, it is also possible to determine a spatially differentiated profile of the absolute magnitudes of the strength of the irradiation, which can be used in particular for an optimized adjustment, for the monitoring of the EUV light source, as well as for monitoring the degree of contamination of the facet mirror or of a preceding mirror.

In a further advantageous embodiment of the invention, one or more sensor elements are used in combination with one or more aperture stop and sensor arrangements for the observation of the light source or one of its intermediate images.

Figure 11 illustrates two aperture stop and sensor arrangements 1.1 and 1.2 which are designed as an assembly unit. This assembly unit, which is of compact dimensions, occupies only a small solid angle space even with a short object distance, so that the assembly unit can be positioned advantageously in a collector below a minimal aperture. The reference symbols again identify two pinholes through which imaging ray bundles fall into the aperture stop and sensor arrangements 1.1 and 1.2. Figure 8 shows the respective gravity-center rays of the ray bundles. Each of the aperture stop and sensor arrangements includes at least one reflective optical element 17 on which the imaging ray bundle is reflected so that the light is redirected in a space-saving manner to the EUV position sensors 2.3, which in the case of the two aperture stop and sensor arrangements 1.1 and 1.2 are essentially bordering on each other.

The measuring method according to the invention, by means of which one or more aperture stop and sensor arrangements determine the source point and the source power of an EUV light source 3 or of an intermediate image 7 of an EUV light source 3 in an EUV illumination system is used for the purpose of controlling, adjusting or regulating the position of the source point of the EUV light source 3 or of the collector optics or parts thereof, or of further optical components following downstream in the system. In addition or as an alternative, a sensor element is used which on at least one mirror detects the generation of photo electrons as a function of location. This provides in particular the possibility during operation of the EUV illumination system to keep an intermediate image of the EUV light source within a defined area around a reference position by means of a servo-regulated position control. According to a further embodiment, the source power of an EUV light source 3 is adapted during operation.

The scope of the invention further includes the disclosure of a projection exposure apparatus for microlithography applications, wherein the illumination system includes a measuring system according to the invention with at least one aperture stop and sensor arrangement. Also disclosed is a method for the manufacture of micro-electronic components, in particular semiconductor chips, with this type of a projection exposure apparatus.

List of Reference Symbols

1, 1.1, 1.2, 1.3	aperture stop and sensor arrangements
2.1	aperture opening
2.2	spectral filter element
2.3	position detector
2.4	particle filter
3	EUV light source
3.1, 3.2	positions of the EUV light source outside of the reference position
4	image of the EUV light source
5	collector
5.1	collector shell
5.2	passage opening in the collector shell
6	minimal numerical aperture
7	intermediate image
7.1, 7.2	first and second intermediate images
9.1, 9.2	aperture stops
11	optical axis
12	multi-layer mirror
13	reference ray
15	imaging ray
17	reflective optical component
19	spectral grid filter
22	field plane
26	projection objective
28	image plane
29.1, 29.2	facet mirror
30.1, 30.2	imaging mirrors
32	field-forming grazing-incidence mirror
34	anode ring
36	electrodes of the anode ring
38	mirror surface
39.1, 39.2	mirror facet of a facet mirror
40	heat inflow
42	heat outflow

44	quadrant detector
48	pair of magnet poles
50	cooling device
52	preamplifier
53	ampere meter
54	signal-evaluation electronics
A, B, C, D	sensor fields of a quadrant sensor
Z_1	object distance
Z_2	design length of the aperture stop and sensor arrangement
β	angle relative to the optical axis
Δx_a, Δx_{a1}, Δx_{a2}	measurement uncertainty of lateral position
Δx_q	source dimension
Δx_1	opening width of aperture stop
Δx_d	resolution on the EUV position sensor
Δz_a	measurement uncertainty of axial position

Patent Claims

1. EUV illumination system with at least one EUV light source (3); with an aperture stop and sensor arrangement (1) for the measurement of intensity fluctuations and/or position changes of the EUV light source (3), in particular in the range of the effectively utilized wavelengths, or of one of the intermediate images of the EUV light source (3), wherein the aperture stop and sensor arrangement (1) comprises an aperture stop (2.1) and an EUV position sensor (2.3); wherein the aperture stop and sensor arrangement (1) is arranged in such away that the aperture stop (2.1) allows a certain solid angle range of the radiation originating from the EUV light source (3) or from one of its intermediate image (7) to fall on the EUV position sensor (2.3).

2. EUV illumination system according to claim 1, characterized in that the aperture stop and sensor arrangement (1) is designed according to the principle of a pinhole camera.

3. EUV illumination system according to one of the claims 1 to 2, characterized in that the EUV illumination system comprises at least two aperture stop and sensor arrangements (1.1, 1.2).

4. EUV illumination system according to one of the claims 1 to 3, characterized in that an aperture stop and sensor arrangement (1) which observes the EUV light source is oriented substantially along the optical axis (11).

5. EUV illumination system according to one of the claims 1 to 3, characterized in that at least one aperture stop and sensor arrangement (1) which observes the EUV light source (3) is oriented at an angle (β) relative to the optical axis.

6. EUV illumination system according to claim 5, characterized in that the aperture stop and sensor arrangement (1) comprises a first aperture stop and sensor arrangement (1.1) which is oriented substantially along the optical axis (11) and a second aperture stop and sensor arrangement (1.2) which is oriented at an angle (β) relative to the optical axis.

7. EUV illumination system according to one of the claims 1 to 6, characterized in that the EUV illumination system comprises a collector (5) which in a solid angle range below a minimal numerical aperture collects no light from the EUV light source (3), and further characterized in that at least one aperture stop and sensor arrangement (1) which observes the EUV light source (3) is positioned in said unused solid angle range below the minimal aperture.

8. EUV illumination system according to one of the claims 1 to 7, characterized in that at least one aperture stop and sensor arrangement (1) receives light from the EUV light source (3) by way of a passage opening (5.2) in a collector mirror.

9. EUV illumination system according to claim 8, characterized in that the passage opening (5.2) in a

collector mirror serves as aperture stop opening (2.1) of the aperture stop and sensor arrangement.

10. EUV illumination system according to one of the claims 1 to 9, characterized in that the EUV illumination system comprises a collector (5), and that at least one aperture stop and sensor arrangement (1) observes the EUV light source (3), and further that the ray bundle of the imaging light is reflected at least once on a mirror surface (38) of the collector (5).

11. EUV illumination system according to one of the claims 1 to 3, characterized in that an aperture stop and sensor arrangement (1) which observes an intermediate image (7) of the EUV light source (3) is oriented substantially along the optical axis (11).

12. EUV illumination system according to one of the claims 1 to 4, characterized in that at least one aperture stop and sensor arrangement (1) which observes an intermediate image (7) of the EUV light source (3) is oriented at an angle (β) to the optical axis (11).

13. EUV illumination system according to claim 3, characterized in that at least two aperture stop and sensor arrangements (1.1, 1.2) observe an intermediate image (7) of the EUV light source (3) from different directions.

14. EUV illumination system according to claim 3, characterized in that at least one aperture stop and sensor arrangement (1.1) observes the EUV light source (3) and at least one further aperture stop and sensor

arrangement (1.2) observes an intermediate image (7) of the EUV light source (3).

15. EUV illumination system according to claim 3, characterized in that the EUV illumination system produces a first intermediate image (7.1) and a second intermediate image (7.2) of the EUV light source (3) and that at least one aperture stop and sensor arrangement (1.1) observes the first intermediate image (7.1) and at least one further aperture stop and sensor arrangement (1.2) observes the second intermediate image (7.2).

16. EUV illumination system according to one of the claims 1 to 15, characterized in that the aperture stop and sensor arrangement (1) comprises a spectral filter element (2.2) serving to filter out unwanted wavelengths outside of the EUV range of wavelengths.

17. EUV illumination system according to claim 16, characterized in that the spectral filter element (2.2) is a foil filter.

18. EUV illumination system according to claim 17, characterized in that the foil filter contains zirconium.

19. EUV illumination system according to claim 16, characterized in that the spectral filter element (2.2) comprises a spectral grid filter and/or a multi-layer mirror.

20. EUV illumination system according to one of the claims 1 to 19, characterized in that the aperture stop and sensor arrangement comprises a device for the deflection of charged particles.

21. EUV illumination system according to one of the claims 1 to 20, characterized in that the aperture stop and sensor arrangement (1) comprises an EUV position sensor (2.3) with a single sensor field or with a plurality of sensor fields which are arranged in the form of a row or matrix and which are preferably configured as quadrant detectors.

22. EUV illumination system according to claim 21, characterized in that the sensor field of the EUV position sensor (2.3) comprises an EUV-sensitive diode or a combination of a fluorescent screen and a camera, or a multi-channel plate.

23. EUV illumination system according to claim 21, characterized in that the EUV position sensor (2.3) comprises a sensor field which determines the gravity center of the incident EUV radiation based on the emitted photo electrons or based on the photo current.

24. EUV illumination system according to one of the claims 1 and 14-19, characterized in that the aperture stop and sensor arrangement comprises reflective optical components for the deflection of the ray bundle between aperture stop opening (2.1) and EUV position sensor (2.2).

25. EUV illumination system according to one of the claims 1 to 24, characterized in that at least two aperture stop and sensor arrangements (1) which observe the same light source (3) or the same intermediate image of the light source 3 from different viewing directions are configured as an assembly unit, wherein an aperture stop (2.1) and

an EUV position sensor (2.3) are dedicated to each aperture stop and sensor arrangement (2.1).

26. EUV illumination system according to claim 25, characterized in that the EUV position sensors of the individual aperture stop and sensor arrangements (1) in said assembly unit substantially border on each other.

27. EUV illumination system
27.1 with at least one EUV light source (3);
27.2 with at least one sensor element for determining the photo electron current as a function of location on at least one reflective element of the EUV illumination system, said sensor element comprising an anode ring (34) with separate electrodes (36) which are at the same electrical potential.

28. EUV illumination system
28.1 with at least one EUV light source (3);
28.2 with at least one facet mirror (29.1);
28.3 wherein at least one facet (39.2) of the facet mirror (29.1) comprises a measurement device (53) for determining the photo current.

29. EUV illumination system according to claim 27 or 28 with at least one aperture stop and sensor arrangement (1) according to one of the claims 1 to 28.

30. EUV illumination system according to one of the claims 1 to 29, characterized in that the EUV light source (3) is a plasma light source.

31. EUV illumination system according to one of the claims 1 to 30, characterized in that the EUV illumination system

comprises a collector (5) as well as a measuring system which captures the movements and/or the deformation of the collector optics and/or of the reflective optical components that follow the collector optics.

32. Method for monitoring an EUV light source (3) in an EUV illumination system, characterized by at least one aperture stop and sensor arrangement (1) serving to determine, in particular at the effectively utilized wavelength, the source point deviation of the EUV light source (3) from a reference position and/or the deviation of the position of one of the intermediate images (7) of the EUV light source (3) from a reference position and/or to determine the source point power of the EUV light source (3) and/or to determine the radiation strength of one of the intermediate images (7) of the EUV light source (3).

33. Method for monitoring an EUV light source (3) according to claim 32, characterized in that at least two aperture stop and sensor arrangement (1) are being used.

34. Projection exposure apparatus for microlithography with an illumination system according to one of the claims 1 to 31 as well as with a mask, a projection objective (26), and a light-sensitive object, in particular a wafer on a carrier system.

35. Method for the manufacture of micro-electronic components, in particular semiconductor chips, with a projection exposure apparatus according to claim 34.

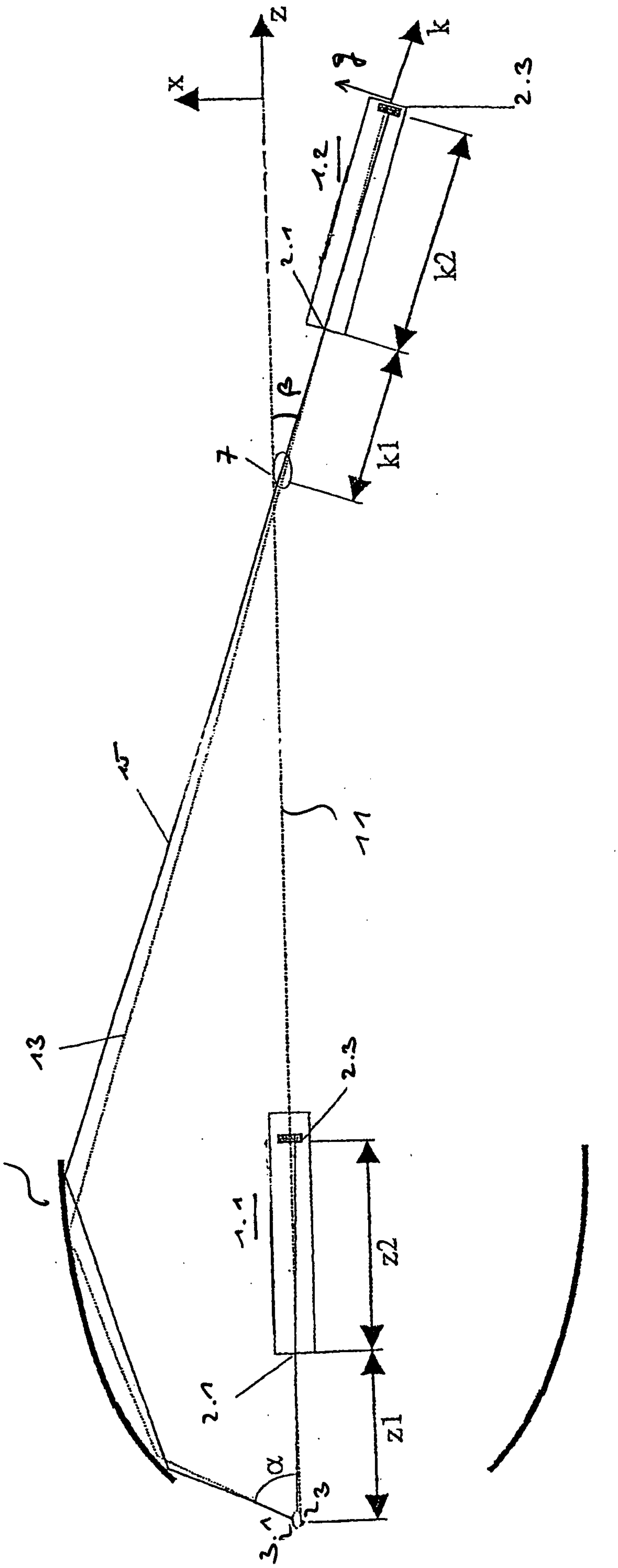
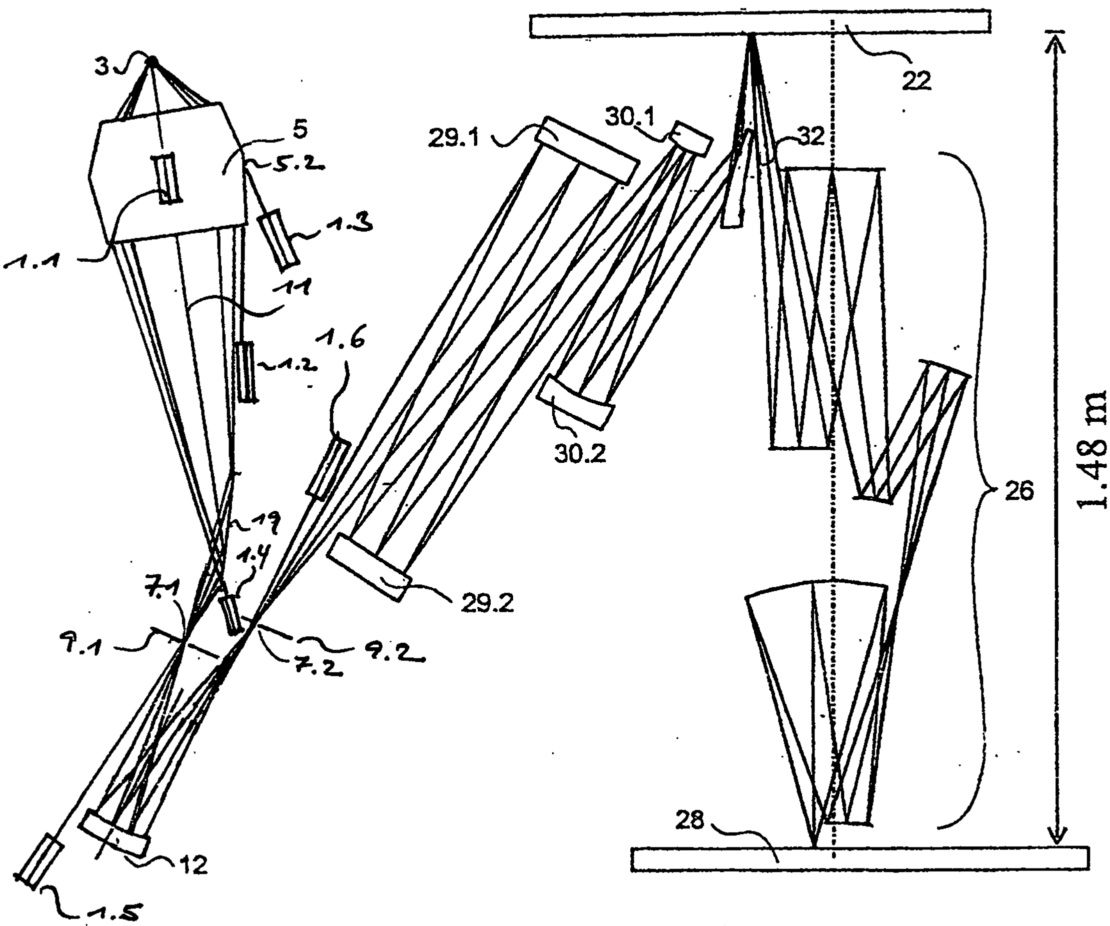


Fig. 1

Fig. 2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1.1
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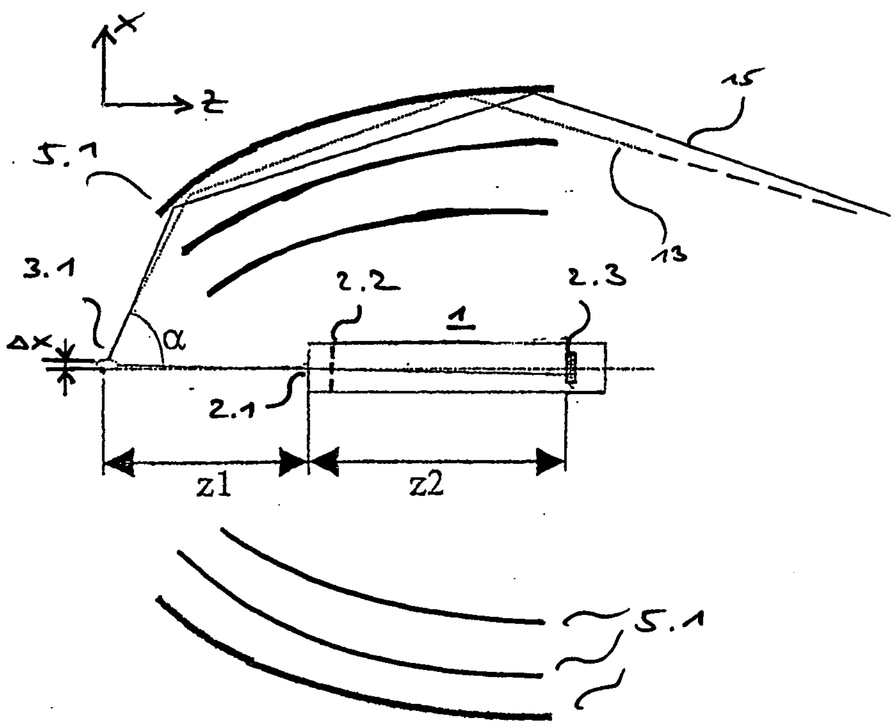
28

Fig. 3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α
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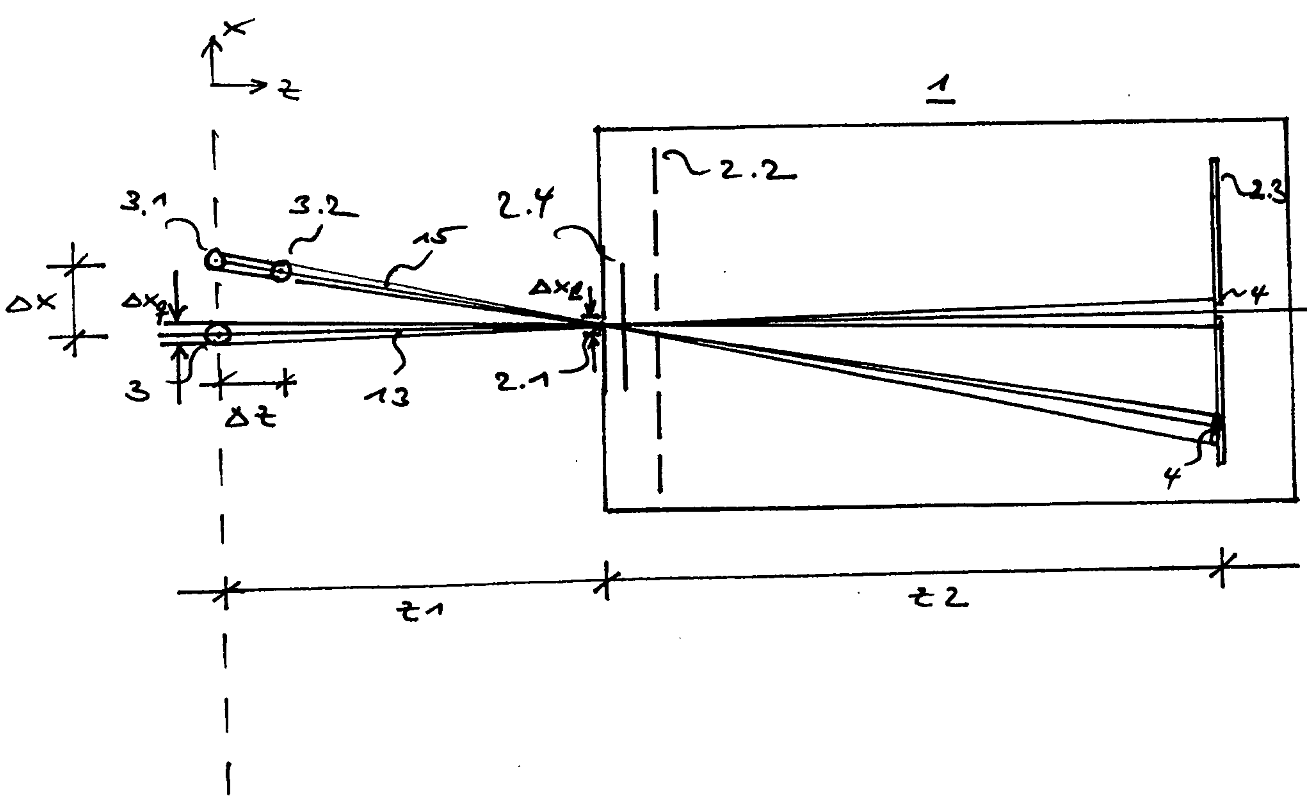
5.1

Fig. 4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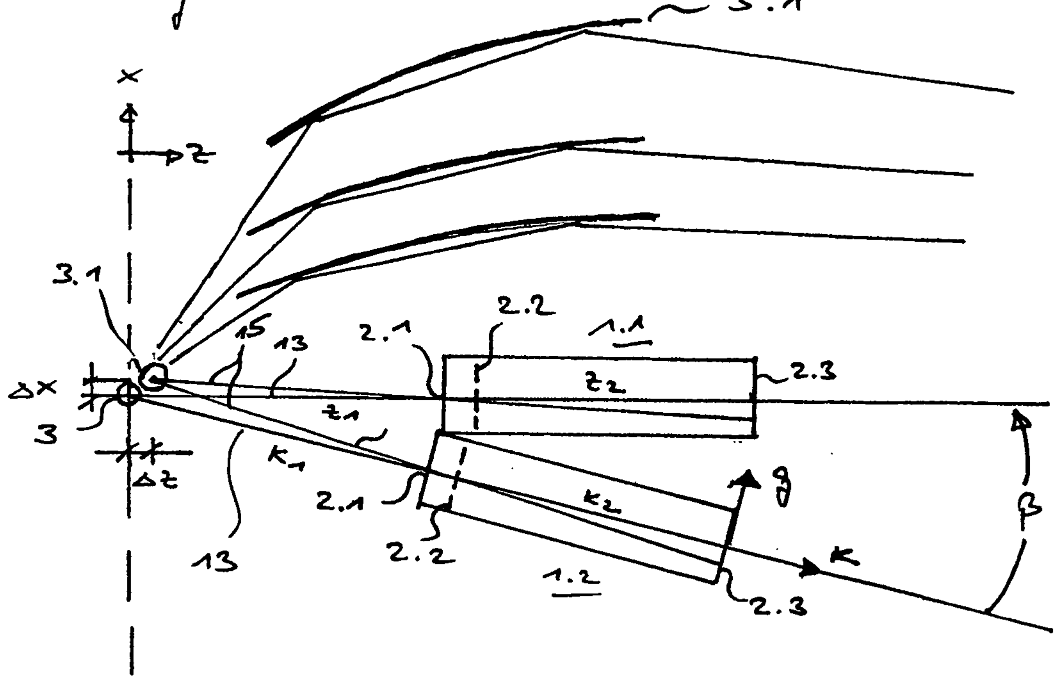
z2

Fig. 5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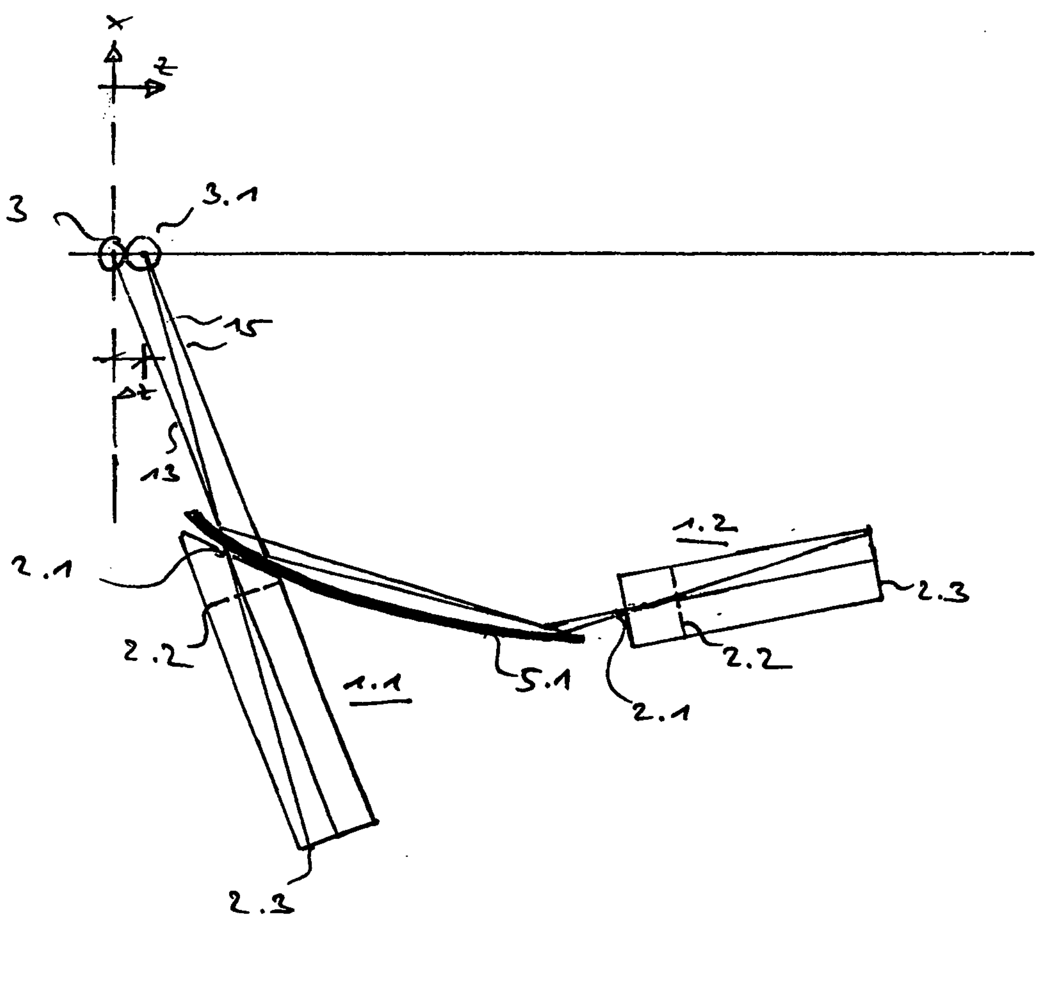
g
β
13
2.2
1.2
2.3
K

Fig. 6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2.1
2.3

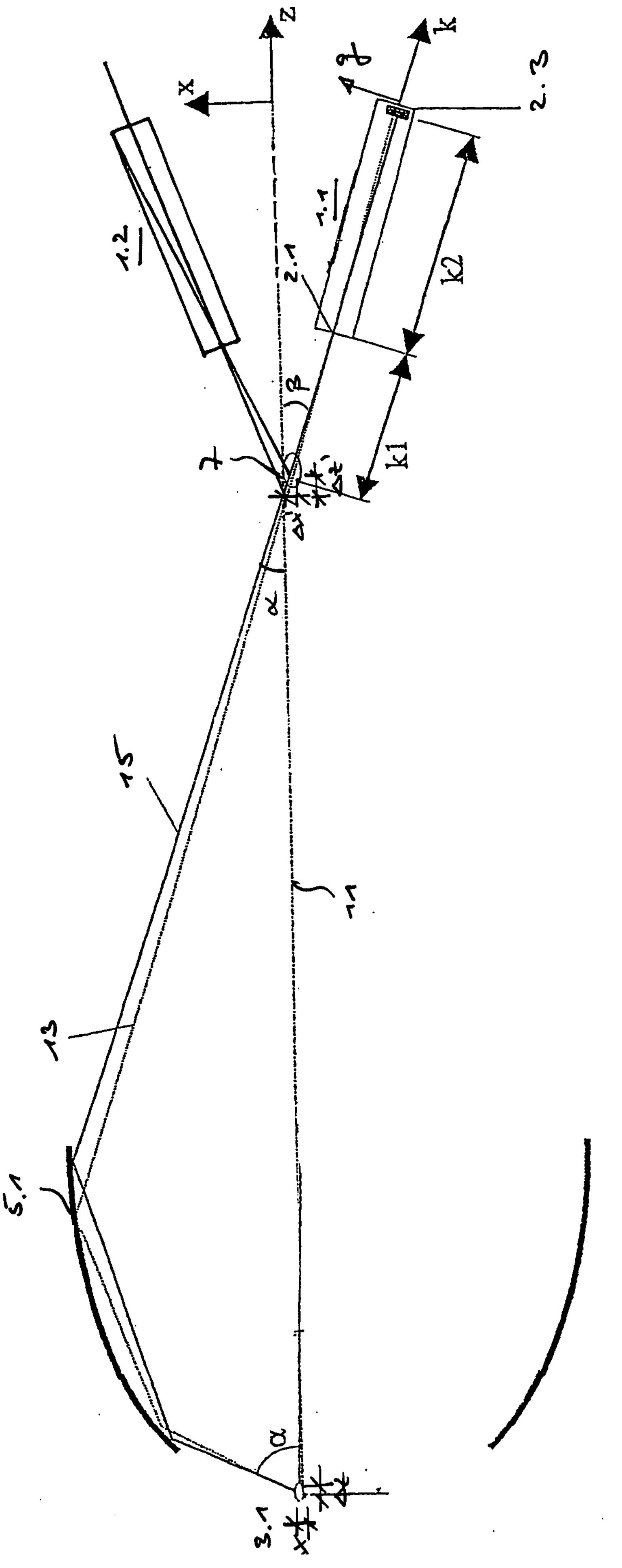
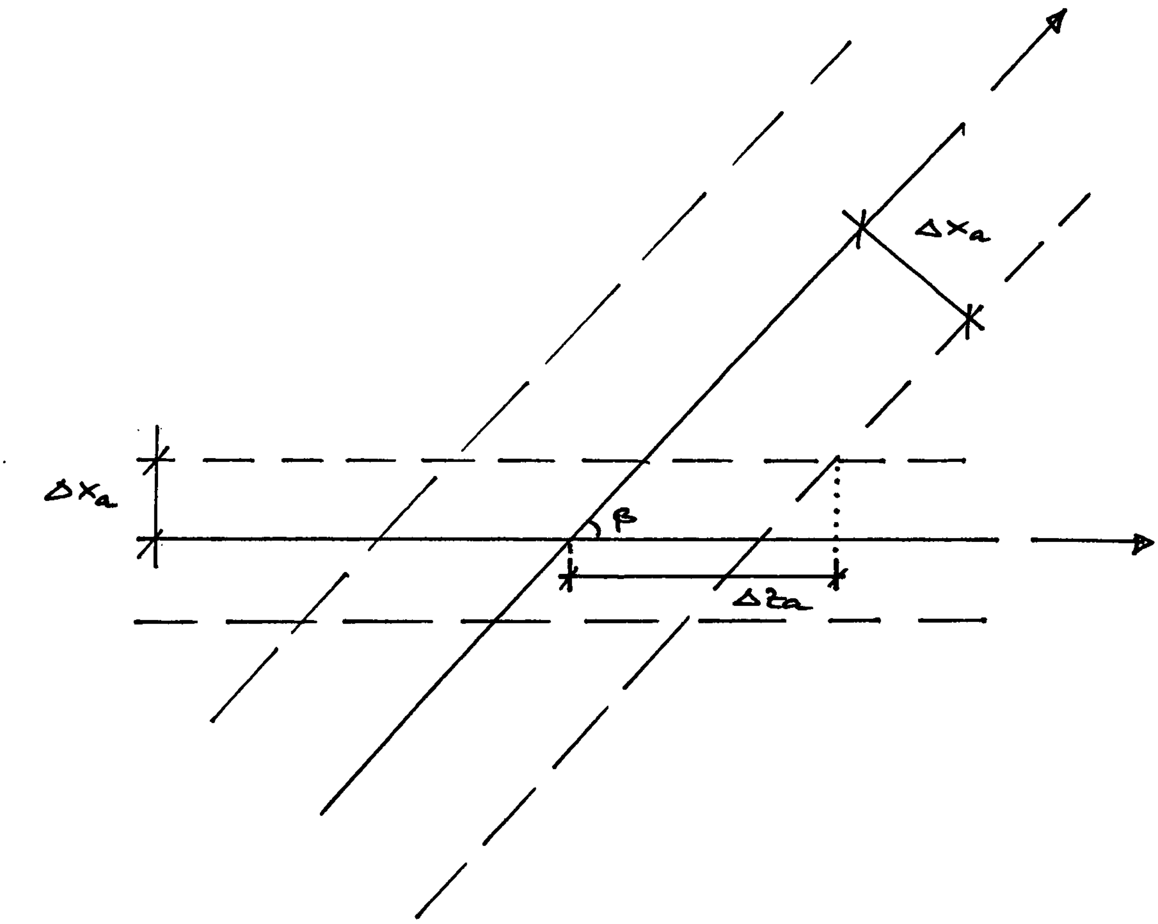


Fig. 7

Fig. 8



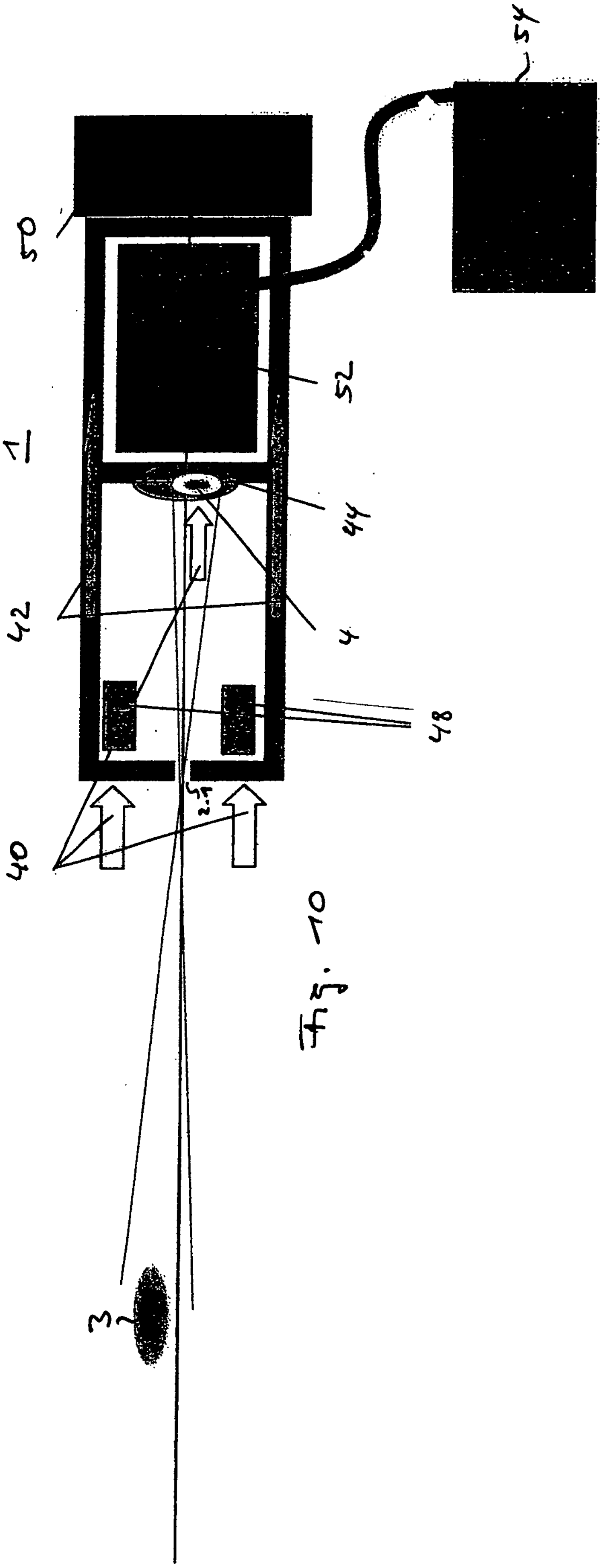


Fig. 10

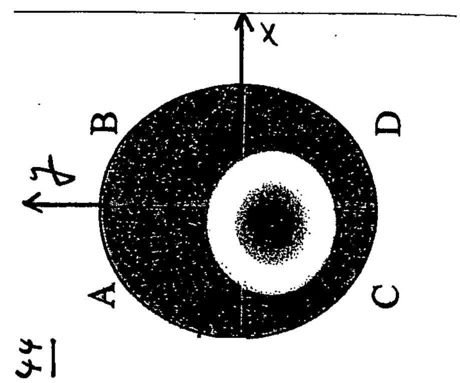


Fig. 9

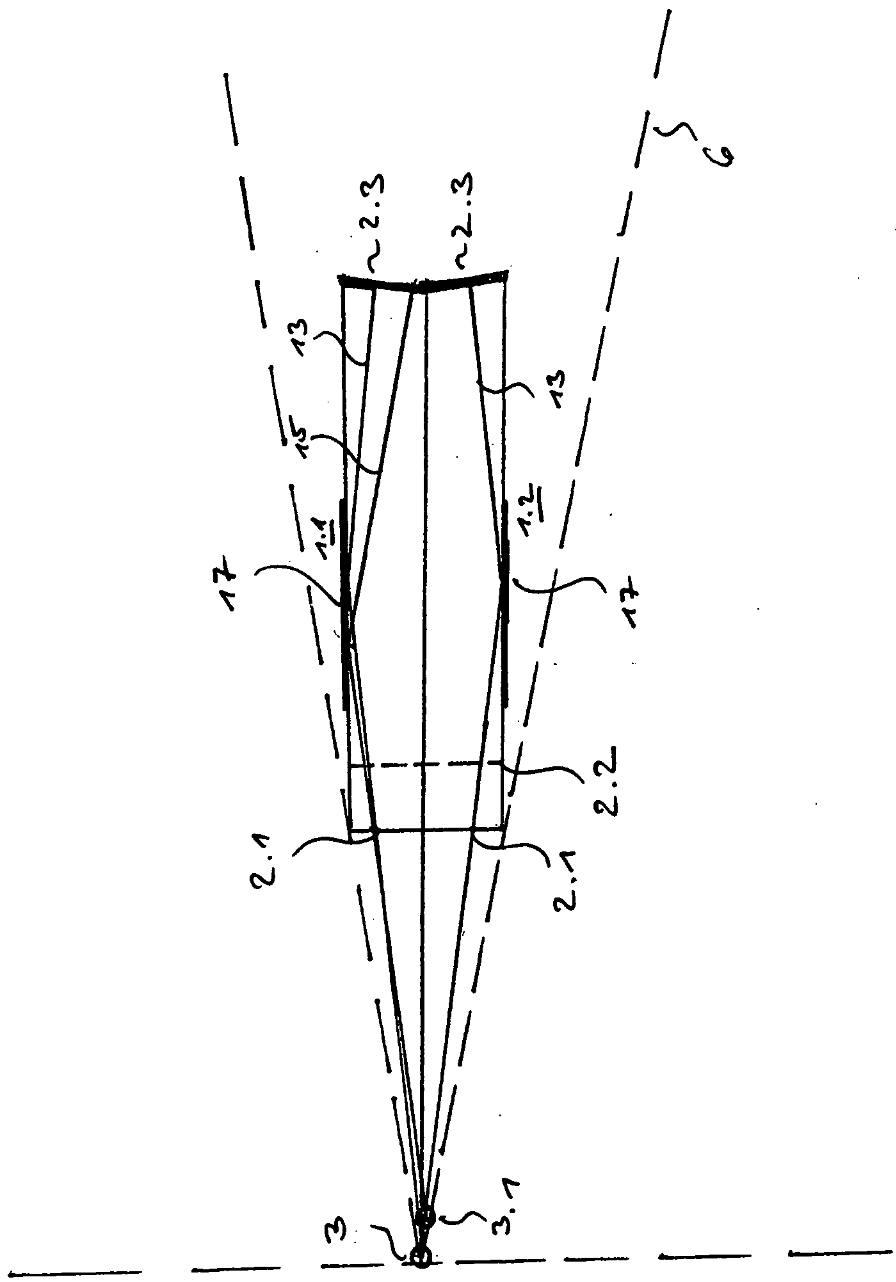


Fig. 11

Fig. 12

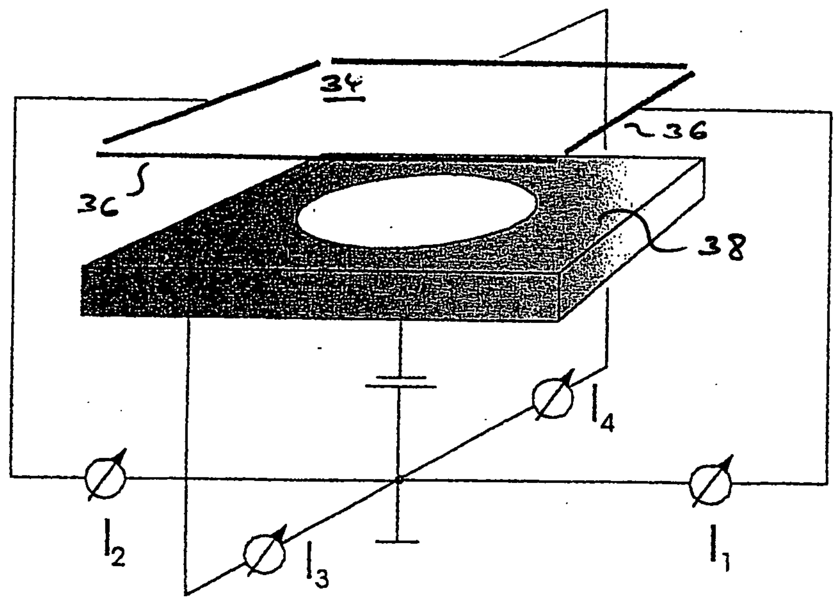
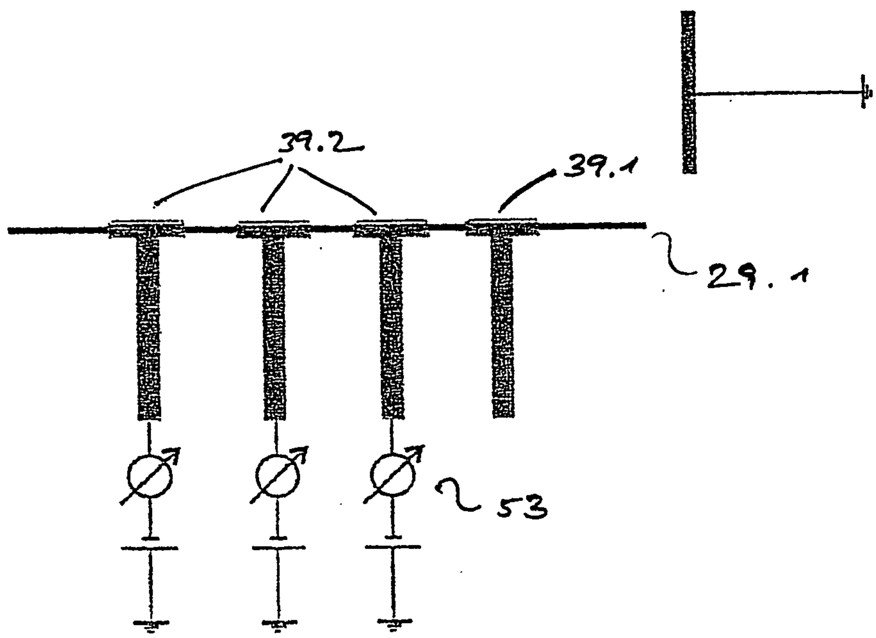


Fig. 13



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2006/010725

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20

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)
G03F G02B H01L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2004/031854 A2 (ZEISS CARL SMT AG [DE]; ASML NETHERLANDS BV [NL]; SINGER WOLFGANG [DE]) 15 April 2004 (2004-04-15) abstract figures 1,3a,3b,3c page 15, lines 8-12 page 24, lines 1-7 page 26, lines 8-14 page 10, lines 26,27 page 20, lines 3-5 ----- -/--	1,3,4, 8-10,16, 19, 21-23, 30-35

[X] Further documents are listed in the continuation of Box C.

[X] 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 document 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

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Date of the actual completion of the international search	Date of mailing of the international search report
25 January 2007	12/02/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Menck, Alexander

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International application No
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