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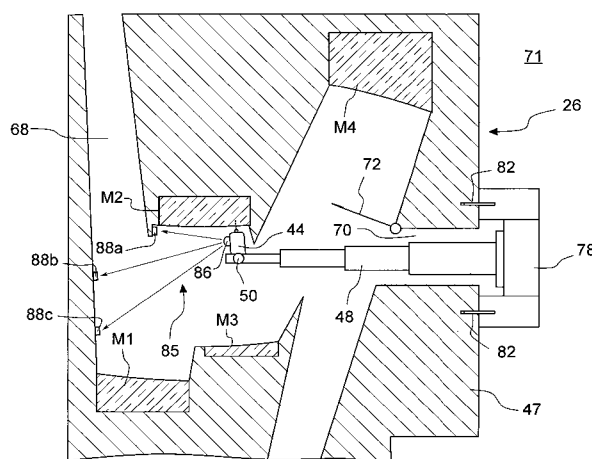


Fig. 6

(57) Abstract: A microlithographic projection exposure apparatus (10) for projecting a reflective mask (14) onto a light-sensitive layer (16) contains a catoptric lens (26) comprising a plurality of mutually adjusted mirrors (M1 to M6) configured to reflect projection light having a center wavelength of between 5 nm and 30 nm. The lens (26) is configured to direct projection light reflected from the mask (14) onto the light-sensitive layer (16). At least one of the plurality of mirrors (M2, M3) is a correction mirror for correcting wavefront deformations, which changes its form permanently when it is processed by a processing beam (65). Furthermore, a processing device (42) is provided, having a processing head (44), from which the processing beam (65) emerges during operation of the processing head. The processing head is arranged or can be arranged within the lens (26) such that the processing beam (65) impinges on none of the other plurality of mirrors before it processes the correction mirror (M2, M3).



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MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS AND
METHOD FOR VARYING AN OPTICAL WAVEFRONT
IN A CATOPTRIC LENS OF SUCH AN APPARATUS

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BACKGROUND OF THE INVENTION

1. Field of the invention

The invention relates to a microlithographic EUV projection exposure apparatus, and to a method for varying an optical
5 wavefront in a catoptric lens of such an apparatus.

2. Description of the prior art

Microlithographic projection exposure apparatuses are used to transfer structures contained in a mask or formed thereon to a photoresist or some other light-sensitive layer. The most
10 important optical components of a projection exposure apparatus are a light source, an illumination system, which conditions projection light generated by the light source and directs it onto the mask, and a lens, which images that section of the mask which is illuminated by the illumination system
15 onto the light-sensitive layer.

The shorter the wavelength of the projection light, the smaller the structures that can be defined on the light-sensitive layer with the aid of the projection exposure apparatus. The most recent generation of projection exposure apparatuses uses projection light in the extreme ultraviolet
20 spectral range (EUV), the center wavelength of which is 13.5 nm. Such apparatuses are often referred to as EUV projection exposure apparatuses.

However, there are no optical materials which have a sufficiently high transmissivity for such short wavelengths. Therefore, in EUV projection exposure apparatuses the lens elements and other refractive optical elements that are customary at longer wavelengths are replaced by mirrors, and also the mask contains a pattern of reflective structures. Lenses containing exclusively mirrors as imaging optical elements are designated as catoptric lenses.

In order to ensure an optimum imaging of the structures contained in the mask onto the light-sensitive layer, extremely stringent requirements are made of the dimensional accuracy of the mirrors in the lens. Nevertheless, owing to manufacturing and mounting tolerances, the minimum imaging aberrations governed by the lens design are never quite reached.

Imaging aberrations of lenses are often described as a deviation of a usually measured real optical wavefront from an ideal optical wavefront. Such deviations, also referred to as wavefront deformations, can be decomposed into individual portions e.g. as a series expansion. In this case, in particular, a decomposition according to Zernike coefficients has proved to be suitable since the individual terms of the decomposition can be assigned directly to specific Seidel imaging aberrations such as astigmatism or coma.

In order to correct imaging aberrations, the mirrors contained in the lens can be adjusted very finely with the aid of manipulators, which encompasses both displacements and flexing of the mirrors. However, only comparatively long-wave portions of the wavefront deformations can be reduced with such measures.

A need for correction can also arise after the start-up of the projection exposure apparatus. This is because it has been ascertained, for example, that the high-energy EUV projection light, at locations of the mirror substrates which

are subjected to a particularly high light intensity over a relatively long time, leads to compaction, which is associated with a locally delimited change in the form of the mirror surface. Therefore, there is occasionally a need to be able to improve the imaging properties of the lens also after the start-up of the projection exposure apparatus.

One approach for correcting short-wave wavefront deformations consists in locally removing the surface on suitable mirrors in order to change the form of the mirror and thereby to reduce or influence the wavefront deformations such that they can be corrected more easily by the manipulators already mentioned.

Such postprocessing by material removal, such as is successfully employed in the case of lens elements, is problematic, however, for a number of reasons in the case of EUV lenses. Firstly, although a material removal changes the form of the relevant mirror, at the same time the sensitive reflective coating is damaged, which leads to a local reduction of the reflection coefficient. One approach for solving this problem consists in locally postprocessing the mirror substrate, rather than the coating itself, as is known from US 2005/0134980 A1.

Another approach consists not in removing material from the mirror surface, but rather locally compacting the mirror substrate below the reflective coating, as is described in DE 10 2011 084 117 A1. For this purpose, a processing beam, e.g. an electron beam or a high-energy light beam, is directed onto the mirror to be processed. The processing beam penetrates through the reflective coating without appreciably interacting therewith, and leads to compaction in the underlying region of the mirror substrate. The associated local contraction of the substrate finally brings about the desired deformation of the mirror.

In both approaches the fundamental problems remains, however, that any type of postprocessing initially requires the incorporation of the mirror into the lens, in order to determine the need for correction and the required postprocessing. If
5 the relevant mirror is then demounted from the lens, post-processed and later incorporated again, then conditions present when ascertaining the need for correction can no longer be totally reproduced. The demounting and later incorporation of the mirror itself might therefore be said to act like a
10 type of additional, but undesirable and uncontrollable postprocessing. Moreover, this problem cannot be circumvented by not postprocessing the mirror used when ascertaining the need for correction, but rather an identical duplicate thereof, as proposed in US 2005/0134980 A1 already mentioned.

15 For projection exposure apparatuses which are designed for projection light having significantly longer center wavelengths and therefore predominantly contain lens elements as optical elements, DE 10 2004 046 542 A1 proposes coupling processing radiation into the lens either from the light entrance side thereof or the light exit side thereof. In this
20 case, the optical properties of the lens elements are taken into account such that those radiation intensities which are required for a local material shrinkage and/or increasing the refractive index occur only on a desired correction lens element. As a result, the other lens elements through which the
25 radiation passes are not processed by the processing radiation.

Such a method cannot be employed in EUV lenses, however, since, although the coatings of the mirrors are reflective to
30 the EUV projection light, they are not reflective to the processing radiation. As a result, no internal mirrors can be processed in this way.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a microlithographic projection exposure apparatus with which even short-wave wavefront deformations can be effectively reduced. It is
5 furthermore an object of the invention to provide a method which makes it possible to efficiently vary optical wavefronts in a catoptric lens of such an apparatus.

This object is achieved by a microlithographic projection exposure apparatus for projecting a reflective mask onto a
10 light-sensitive layer, this apparatus comprising a catoptric lens comprising a plurality of mutually adjusted mirrors. The mirrors are preferably configured to reflect projection light having a center wavelength of between 5 nm and 30 nm. The lens is configured to direct projection light reflected from
15 the mask onto the light-sensitive layer. At least one of the plurality of mirrors is a correction mirror for correcting wavefront deformations, which permanently changes its form when it is processed with a processing beam. The projection exposure apparatus furthermore comprises a processing device
20 comprising a processing head, from which the processing beam emerges during operation of the processing head. The processing head is arranged or can be arranged within the lens such that the processing beam impinges on none of the other plurality of mirrors before it processes the correction mirror.

25 The invention is based on the consideration that an effective correction of wavefront deformations is possible only if the correction mirror to be processed remains in the lens after the need for correction has been determined. Since, on the other hand, the processing beams suitable for processing are
30 not reflected by the mirrors, for the purpose of processing the internal mirrors the processing beam must emerge from a processing head arranged in the lens. In this case, the processing head can either be arranged permanently in the lens or

be situated within the lens only during the actual processing. In this case, the processing head is introduced into the lens in such a way that the latter does not have to be disassembled. Consequently, an impairment of the imaging properties, as is usually unavoidable in the case of demounting and
5 later renewed incorporation of a mirror, cannot occur.

Consequently, the invention makes it possible for even an internal mirror, i.e. a mirror that is neither the first nor the last mirror in the beam path of the lens, to be postprocessed for correction purposes, without said mirror having to
10 be demounted from the lens for the postprocessing.

The processing beam preferably has the property that it compacts only the mirror substrate, but not the reflective coating, if it impinges on the reflective coating. In particular,
15 an electron beam or a light beam having sufficiently high energy is appropriate as processing beam.

If the processing beam is a high-energy light beam, then the latter can be guided with the aid of a tiltable mirror or the like in a targeted manner in a scanner-like manner over the
20 area to be processed of the correction mirror. Particularly when the processing beam is an electron beam, however, it can be expedient to move the processing head across the area of the correction mirror with the aid of a moving device. The relatively short processing distances that are expedient in
25 the case of processing using electron beams, in order to keep the diameter of the electron beam small, can be realized without any problems in this way.

In particular, the moving device can be configured to move the processing head across the area of the correction mirror
30 such that the distance between the processing head and the area does not exceed a maximum processing distance of 10 mm, preferably of 5 mm, and with further preference of 1 mm during a processing of the correction mirror with the processing

beam. In this way, it is possible to produce even locally very narrowerly delimited compactions in the substrate material with the aid of the processing beam.

5 If, despite the small beam diameter, relatively large areas are intended to be processed continuously, then the processing device can be configured to move the processing head across the area along a movement path such that after covering the movement path the processing beam has progressively processed a volume adjacent to a two-dimensional region on
10 the area.

In general, the area processed by the processing beam will be a surface of the reflective coating which is carried by a mirror substrate. This ensures that the compaction of the mirror substrate is situated in direct proximity to the reflective coating and can therefore exert its maximum effect
15 on the optical wavefront.

In principle, however, the processing beam can also impinge on an area of the correction element which is not covered by the reflective coating. Said area can be, for example, an
20 area on the rear side of the mirror substrate which faces away from the reflective coating. Such processing areas are advantageous, under certain circumstances, with regard to the structural space required for arranging the processing head in the lens.

25 If the processing head is not arranged permanently in the lens, the latter can have a support structure for supporting the plurality of mirrors, an access channel being formed in said support structure. The processing head can then be introduced into the lens through the access channel when processing of the correction mirror with the aid of the processing
30 beam is intended to be performed. By virtue of the access channel that is constantly present, therefore, there is no need for any structural alterations of the lens whatsoever in

order to be able to carry out the processing. This ensures that even after processing all mirrors are situated exactly at the location at which they were situated when the need for correction was determined. The access channel be a light
5 channel that is provided anyway for the passage of the projection light. It is even more expedient, however, if the access channel is provided in addition to such a light channel.

Introducing the processing head into the lens only during the
10 actual processing times can be practical for a number of reasons. Firstly, the processing head can then be arranged during processing in the light channel that is actually designed for the passage of the projection light and preferably differs from the access channel. In the case of a processing
15 head arranged permanently in the lens, by contrast, it must be ensured that, at least during projection operation, the processing head is in a rest position in which it does not impede the passage of the projection light. This may be difficult from standpoints of structural space depending on lens
20 design. A further advantage of the processing head being arranged only as necessary in the lens is that with only one processing head it is also possible to process different correction mirrors.

With regard to the method, the object mentioned in the introduction is achieved by means of a method for varying an optical wavefront in a catoptric lens of a microlithographic projection exposure apparatus, wherein the method comprises the following steps:

- a) assembling the catoptric lens from a plurality of mirrors, which are preferably designed to reflect projection light having a center wavelength of between 5 nm and 30 nm, and wherein at least one of the plurality of
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mirrors is a correction mirror for correcting wavefront deformations;

b) adjusting the mirrors;

5 c) processing an area of the correction mirror with a processing beam, whereby the form of the correction mirror changes permanently, and wherein the processing beam impinges on none of the other plurality of mirrors before it processes the correction mirror;

10 wherein between steps b) and c) no mirrors are removed from the lens.

Reference is made to the above-explained advantages and preferred embodiment.

15 In particular, a processing head, which emits the processing beam, can be moved across the area of the correction mirror during step c) such that the distance between the processing head and the area does not exceed an optimum processing distance of 10 mm, preferably of 5 mm, with further preference of 1 mm during a processing of the correction mirror with the processing beam.

20 During step c), the processing beam can be guided over the area such that after covering the movement path the processing beam has progressively processed a two-dimensional region on the area.

25 If the processing head is situated in the lens only during processing, then said processing head can be introduced into the lens through an access channel before processing, said access channel being provided in a support structure configured to support the mirrors and which differs from a light channel designed for the passage of the projection light
30 through the lens.

The invention additionally relates to a lens comprising a mirror, a processing head, which is configured to emit a processing beam, and comprising a moving device, which is configured to arrange the processing head at different locations over an area of the mirror such that the processing beam brings about a permanent change in the form of the mirror.

In one embodiment, in this case the distance between the processing head and the area of the mirror does not exceed a maximum processing distance of 10 mm.

The invention furthermore relates to a method for varying an optical wavefront in a lens, comprising the following steps:

- a) assembling a catoptric lens from a plurality of mirrors;
- b) adjusting the mirrors;
- c) directing a processing beam onto an area of a mirror, whereby the form thereof changes permanently, wherein the mirror is neither the first nor the last mirror of the lens in the beam path of the lens.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features and advantages of the invention are evident from the following description of embodiments with reference to the drawings, in which:

Figure 1 shows a schematic perspective view of an EUV projection exposure apparatus according to the invention;

Figure 2 shows a meridional section through the lens of the projection exposure apparatus shown in Figure 1 in accordance with the first embodiment, the processing head being in an inactive position;

Figure 3 shows the meridional section from Figure 2, the processing head being in an active position;

Figures 4a to 4c show sections through a correction mirror contained in the lens before, during and after processing with a processing beam;

Figure 5 shows a meridional section through a part of the lens of the projection exposure apparatus shown in Figure 1 in accordance with a second embodiment, the processing head being situated outside the lens;

Figure 6 shows the meridional section from Figure 5, the processing head being situated within the lens;

Figure 7 shows a flow chart listing important steps of the method according to the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

1. Basic construction of the projection exposure apparatus

Figure 1 shows, in a perspective and highly schematic illustration not to scale, the basic construction of a microlithographic projection exposure apparatus according to the invention, said apparatus being designated in its entirety by 10. The projection exposure apparatus 10 serves to project reflective structures 12 arranged on a side of a mask 14 that faces downward in Figure 1 to a light-sensitive layer 16. The light-sensitive layer 16, which can be, in particular, a photoresist (also called *resist*), is carried by a wafer 18 or some other substrate.

The projection exposure apparatus 10 comprises an illumination system 20, which illuminates that side of the mask 14 which is provided with the structures 12 with EUV light 22. A range of between 5 nm and 30 nm, in particular, is appropri-

ate as wavelength for the EUV light 22; in the present embodiment illustrated, the center wavelength of the EUV light 22 is approximately 13.5 nm. The EUV light 22 illuminates an illumination field 24 on the downwardly facing side of the mask 14, said illumination field having the geometry of a ring segment in the embodiment illustrated.

The projection exposure apparatus 10 furthermore comprises a lens 26, which generates on the light-sensitive layer 16 a reduced image 24' of the structures 12 lying in the region of the illumination field 24. The lens 26 has an optical axis OA, which coincides with the axis of symmetry of the ring-segment-shaped illumination field 24 and is thus situated outside the illumination field 24.

The lens 26 is designed for scanning operation in which the mask 14 is moved synchronously with the wafer 18 during the exposure of the light-sensitive layer 16. These traveling movements of the mask 14 and of the wafer 18 are indicated by arrows A1, A2 in Figure 1. During an exposure of the light-sensitive layer 16, therefore, the illumination field 24 sweeps over the mask 14 in a scanner-like manner, as a result of which even relatively large continuous structure regions can be projected onto the light-sensitive layer 16. The ratio of the speeds at which the mask 14 and the wafer 18 are moved is in this case equal to the imaging scale β of the lens 26. In the embodiment illustrated, the image 24' generated by the lens 20 is reduced ($|\beta| < 1$) and erect ($\beta > 0$), for which reason the wafer 18 is moved more slowly than the mask 14, but in the same direction.

Light beams proceed from each point in the illumination field 24 which is situated in an object plane of the lens 26, said light beams entering into the lens 26. The latter has the effect that the entering light beams converge in an image plane of the lens 26 at field points. The field points in the

object plane from which the light beams proceed, and the field points in the image plane at which said light beams converge again are in this case in a relationship with one another which is designated as optical conjugation.

- 5 For an individual point in the center of the illumination field 24, such a light beam is indicated schematically and designated by 28. In this case, the aperture angle of the light beam 28 upon entering into the lens 26 is a measure of the numerical aperture NA thereof. On account of the reduced
10 imaging, the image-side numerical aperture NA of the lens 26 is enlarged by the reciprocal of the imaging scale β .

Figure 2 shows important components of the lens 26 likewise schematically and not to scale in a meridional section. Between the object plane indicated at 30 and the image plane
15 indicated at 32, a total of six mirrors M1 to M6 are arranged along an optical axis OA. The light beam 28 proceeding from a point in the object plane 30 firstly impinges on a concave first mirror M1, is reflected back onto a convex second mirror M2, impinges on a concave third mirror M3, is reflected
20 back onto a concave fourth mirror M4 and then impinges on a convex fifth mirror M5, which directs the EUV light back onto a concave sixth mirror M6. The latter finally focuses the light beam 28 into a conjugate image point in the image plane 32.

- 25 If the mirrors M1 to M6 were supplemented by the parts indicated by dashed lines in Figure 2, then the reflective surfaces of the mirrors thus supplemented would be rotationally symmetrical with respect to the optical axis OA of the lens 26. As can readily be discerned, the beam path described
30 above could not be realized with such completely rotationally symmetrical mirrors, however, since the mirrors would then partly block the light path. Therefore, the mirrors M1 to M6 have the forms indicated by solid lines.

The lens 26 has a first pupil surface 34, which is situated in or in direct proximity to the surface of the second mirror M2. A pupil surface is distinguished by the fact that there the chief rays of the light beams proceeding from points in the object plane 30 intersect the optical axis OA. This is shown in Figure 2 for the chief ray 36 of the light beam 28, said chief ray being indicated in a dashed fashion.

A second pupil surface 38 is situated in the beam path between the fifth mirror M5 and the sixth mirror M6, wherein the distance from the second pupil surface 38 to these two mirrors M5, M6 is relatively large. A shading diaphragm 40 is arranged at the level of the second pupil surface 38.

2. Processing device

A processing device 42 is arranged in the lens 26, said processing device comprising a processing head 44 and a moving device 46 for moving the processing head 44. In the embodiment illustrated, the processing device 42 is permanently fixed to a support structure 47 of the lens 26. The support structure 47 carries, inter alia, the mirrors M1 to M6 and cooling devices and adjustment manipulators and is schematically indicated merely by its outer contour in Figure 2.

The moving device 46 makes it possible to move the processing head 44 relative to the supporting structure 46 and thus to the mirrors M1 to M6 fixed thereto. In the embodiment illustrated, the moving device 46 comprises a telescopic arm 48 supporting a pivoting device 50 at its free end. With the aid of the pivoting device 50, the processing head 44 can be pivoted about two orthogonal axes in a motor-operated manner. At its end opposite the processing head 44, the telescopic arm 48 is fixed to a motor-operated XY movement stage 52, with the aid of which the telescopic arm 48 with the processing head 44 fixed at the end can be moved translationally along two orthogonal directions. The moving device 46 is able in

this way to guide the processing head 44 close to different locations on the reflective surfaces of the mirrors M2 and M3, as is shown in Figure 3 by solid lines with regard to the second mirror M2 and by dashed lines with regard to the third mirror M3.

It may be expedient for reasons of structural space not to arrange the processing device 42 in the meridional plane shown in Figures 2 and 3, but rather in a sagittal plane - perpendicular thereto - of the lens 26. Moreover, entirely different designs are also appropriate for the moving devices as long as they are suitable for delivering the processing head to at least one of the mirrors M1 to M6 of the lens 26.

In the embodiment illustrated, the processing head 44 contains an electron gun that is conventional per se, such as are used for example in X-ray sources. Such an electron gun usually comprises an electron source, e.g. an incandescent cathode, a Wehnelt cylinder and an acceleration anode in order to accelerate the electrons released by the incandescent cathode. The energy of the electrons emitted by the processing head 44 is preferably in the range of between 5 keV and 80 keV, and in particular between 40 keV and 50 keV. The energy which the emitted electrons should ideally have is dependent, inter alia, on the material of which the substrate of the mirrors M2, M3 consists.

As an alternative to an electron gun, the processing head 44 can also contain a laser, preferably operated in a pulsed fashion, or a light exit window of an optical fiber into which the light from such a laser is coupled. The laser should generate light having a center wavelength of between 0.3 μm and 3 μm and having pulse energies of between 0.01 μJ and 10 μJ ; the repetition rate should be between 1 Hz and 100 MHz.

3. *Function*

The function of the lens 26 and of the processing device 42 is explained below with reference to Figures 3 and 4.

5 Firstly, the lens 26 is assembled and adjusted. In the context of the adjustment, the imaging properties of the lens 26 are generally measured iteratively. This can be done, by way of example, in a manner known per se, by interferometrically determining the optical wavefront in the image plane 32 of the lens 26. During the adjustment, the position of the mirrors M1 to M6 is varied such that the imaging aberrations are minimized. In addition, manipulators, if present, can also be used, which deform one or more of the mirrors M1 to M6 in a targeted manner in order to further reduce the wavefront deformations in this way.

15 Even after such a relatively complex adjustment process, residual imaging aberrations occasionally remain, however, which cannot be tolerated in the case of extremely stringent demands placed on the imaging properties of the lens 26. Said residual imaging aberrations are often short-wave wavefront deformations that are described by higher terms in a decomposition of the wavefront deformations according to Zernike coefficients. Contributions to the residual imaging aberrations which are independent of the field position can be reduced by targeted postprocessing of the second mirror M2 arranged in the first pupil plane 34. The aim of the postprocessing is to deform the second mirror M2 such that the remaining residual imaging aberrations are reduced or converted into longer-wave imaging aberrations that can be corrected with the aid of other manipulators in the abovementioned adjustment process.

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Figure 4a shows the second mirror M2 in an enlarged view in a meridional section. The mirror M2 comprises a mirror substrate 54, which consists of a special glass such as ULE® or

Zerodur® in the embodiment illustrated. Such glasses have a low or vanishing coefficient of thermal expansion at the operating temperature of the mirror M2, with the result that they do not deform in the event of relatively small temperature changes. The mirror substrate 54 has a precisely processed optical area 56 whose form crucially determines the optical properties of the second mirror M2. The optical area 56 carries a reflective coating 58, not illustrated to scale, which comprises a multiplicity of thin individual layers 60 having alternating refractive indices. The reflective coating 58 is designed to reflect the short-wave EUV projection light. The mirror substrate 54 additionally has a circumferential area 62 and a rear area 64, which are not optically active but are important for the dissipation of heat from the second mirror M2.

Figure 4b shows the second mirror M2 during a processing operation with the aid of the processing device 42. In the processing position illustrated, the processing head 44 is situated at a processing distance d from the reflective coating 58 that is less than 10 mm. Such a short processing distance is necessary in order that the divergent electron beam 65 generates a sufficiently small beam spot on the second mirror M2. The high-energy electrons penetrate through the thin reflective coating 58 without appreciably interacting therewith. In the mirror substrate 54 by contrast, the high-energy electrons are absorbed and bring about there a local compaction of the mirror substrate 54. This compaction, in turn, is associated with a deformation 66 of the optical area 56 and of the reflective coating 58 carried thereby, as shown by Figure 4c. This local deformation 66 produces the desired correction of the wavefront and thus contributes to the improvement of the imaging properties of the lens 26.

If deformations 66 are intended to be produced at a plurality of locations of the second mirror M2, the processing head 44

is moved progressively to the corresponding locations with the aid of the moving device 46. A compaction of relatively large regions of the mirror substrate 54 is also possible if the processing head 44 is moved across the optical area 56
5 along a movement path in such a way (e.g. in a meandering manner) that after covering the movement path, the processing beam 65 has progressively processed a two-dimensional region on the optical area 56.

If field-dependent wavefront deformations are also intended
10 to be corrected, a mirror arranged near-field must be processed with the aid of the processing head 44 in the manner outlined above. Since the third mirror M3 is arranged at least outside the pupil plane 34, small field dependencies can be corrected there, as is indicated by dashed lines in
15 Figure 3. Even better suited to this is the fourth mirror M4, which is arranged nearer to the intermediate image.

Since the processing device 42 is integrated into the lens 26, processing for correction purposes can also be carried out without any problems after the projection exposure apparatus 10 has been started up. Such a need for correction may
20 arise, for example, because the high-energy EUV projection light partly penetrates through the reflective coatings 48 of the mirrors M1 to M6 and can likewise lead to a compaction of the mirror substrates 54 if specific light intensities are
25 exceeded over a relatively long period of time. The deformations of the optical area 56 that are associated with the compaction can be compensated for or at least modified by means of suitably designed postprocessing with the aid of the processing device 42 such that remaining residual imaging
30 aberrations can be corrected more easily by other manipulators.

4. *Second embodiment*

A permanent arrangement of the processing device 42 in the lens 26 may be difficult for various reasons. Firstly, on account of the complicated beam path in EUV lenses 26 the available structural space is often so limited that an additional assembly cannot readily be accommodated. From stand-points of costs, too, it may be more advantageous for the processing device 42 to be arranged in the lens 26 only as necessary, rather than permanently.

Referring to Figures 5 and 6, a second embodiment of a processing device 42 according to the invention is described below, in which the processing head 44 is introduced into the lens 26 only as necessary. Figure 5 shows at the top an excerpt from a lens 26, in whose support structure 47 for supporting the mirrors M1 to M6 a light channel 68 is formed, which is provided for the passage of the EUV projection light. In addition to the light channel 68, an access channel 70 is formed in the support structure 47, said access channel connecting the light channel 68 to the external space 71 surrounding the lens 26. During normal projection operation, the light channel 68 is separated from the access channel 70 by a pivoting flap 72; furthermore, a closure cover 74 is provided, which closes off the access channel 70 toward the external space 71.

In this embodiment, the processing device 42, or to put it more precisely the moving device 46 thereof, is fixed to a mount 78 comprising guide elements 80. The guide elements 80 correspond to guide holes 82 formed in the support structure 47 of the lens 26.

If a need for correction that necessitates postprocessing of the second mirror M2 arises after the initial adjustment or at a point in time after the start-up of the projection exposure apparatus 10, then the closure cover 74 is taken away

and the pivoting flap 72 is pivoted up. The access channel 70 then provides a continuous connection between the external space 71 and the light channel 68. Afterward, the mount 78 of the processing device 42 is fixed to the support structure 47 from outside, the guide elements 80 engaging into the guide holes 82, as is shown in Figure 6.

In a next step, the processing head 44 is brought to the desired position relative to the second mirror M2 with the aid of the moving device 46 and the processing is performed with the aid of the processing beam 65.

In order to be able to position the processing head precisely above the optical area 56 of the second mirror M2, in this embodiment the processing device 42 has an additional position detecting device 85, with which the position, i.e. the spatial and angular coordinates, of the processing head 44 relative to the support structure 47 and thus to the second mirror M2 can be measured with high accuracy. For this purpose, the position detecting device 85 is designed as a μ GPS system comprising a light emission device 86, which is arranged on the processing head 44 and to which light is fed from an external light source, and at least three light receiving units 88a, 88b, 88c fixed to the support structure 47 at different locations. By superimposing the light received at the light receiving units 88a, 88b, 88c with reference light generated by the external light source, it is possible to determine the distances between the light receiving units 88a, 88b, 88c and the light emission device 86 with high accuracy. In this way, it is possible to measure the position of the processing head 44 with an accuracy of a few micrometers relative to the second mirror M2. Further details concerning a suitable μ GPS system can be gathered from DE 10 2008 003 282 A1. However, other measuring systems, e.g. conventional measuring systems employing triangulation, are also appropriate for the position detection.

5. *Important method steps*

Important steps of the method according to the invention are summarized in a flow chart shown in Figure 7.

In a first step, a lens 26 is assembled from a plurality of
5 mirrors M1 to M6, wherein at least one of the plurality of
mirrors is a correction mirror for correcting wavefront de-
formations.

Afterward, the mirrors are adjusted in a step S2.

In a subsequent step S3, an area of the correction mirror is
10 processed with a processing beam, whereby the form of the
correction mirror changes permanently. In this case, the
processing beam impinges on none of the other plurality of
mirrors before it processes the correction mirror. Moreover,
after step S2, no mirror is removed from the lens.

CLAIMS

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1. Microlithographic projection exposure apparatus (10)
for projecting a reflective mask (14) onto a light-
sensitive layer (16), comprising
 - a) a catoptric lens (26) comprising a plurality of
mutually adjusted mirrors (M1 to M6) configured
for reflecting projection light having a center
wavelength of between 5 nm and 30 nm, wherein the
lens (26) is configured to direct projection
light reflected from the mask (14) onto the
light-sensitive layer (16), and wherein at least
one of the plurality of mirrors (M2, M3) is a
correction mirror for correcting wavefront defor-
mations, which permanently changes its form when
it is processed with a processing beam (65),
 - b) a processing device (42) comprising a processing
head (44), from which the processing beam (65)
emerges during operation of the processing head,
wherein the processing head is arranged or can be
arranged within the lens (26) such that the proc-
essing beam (65) impinges on none of the other
plurality of mirrors before it processes the cor-
rection mirror (M2, M3).
2. Microlithographic projection exposure apparatus accord-
ing to Claim 1, wherein the correction mirror (M2, M3)
is neither the first nor the last mirror in the beam
path of the lens (26).
3. Microlithographic projection exposure apparatus accord-
ing to Claim 1 or 2, wherein the processing device com-

prises a moving device (46), which is configured to move the processing head (44) in the lens (26) across an area of the correction mirror (M2, M3).

4. Microlithographic projection exposure apparatus according to Claim 3, wherein the moving device (46) is configured to move the processing head (44) across the area of the correction mirror (M2, M3) such that the distance (d) between the processing head (44) and the area does not exceed a maximum processing distance of 10 mm during a processing of the correction mirror with the processing beam.
5. Microlithographic projection exposure apparatus according to any of the preceding claims, wherein the processing head (44) is arranged permanently in the lens (26).
6. Microlithographic projection exposure apparatus according to any of Claims 1 to 4, wherein the lens (26) has a support structure (47) for supporting the plurality of mirrors (M1 to M6), an access channel (70) being formed in said support structure, and wherein the processing head (44) can be introduced into the lens (26) through the access channel (70).
7. Microlithographic projection exposure apparatus according to Claim 3 or 4 and according to Claim 6, wherein the processing head (44) is held by the moving device (46) when it is introduced into the lens (26), and wherein at least one part of the moving device (46) extends through the access channel (70).
8. Microlithographic projection exposure apparatus according to Claim 6 or 7, wherein a light channel (68) for the passage of the projection light is furthermore

formed in the support structure (47), said light channel being different from the access channel (70).

9. Microlithographic projection exposure apparatus according to any of the preceding claims, wherein the processing beam (65) is an electron beam or a light beam.

10. Microlithographic projection exposure apparatus according to any of the preceding claims, comprising a position detecting device (85) configured to detect the position of the processing head (44) relative to the correction mirror (M2, M3) during processing.

11. Method for varying an optical wavefront in a catoptric lens (26) of a microlithographic projection exposure apparatus (10), wherein the method comprises the following steps:

a) assembling the catoptric lens (26) from a plurality of mirrors (M1 to M6), wherein at least one of the plurality of mirrors is a correction mirror (M2, M3) for correcting wavefront deformations;

b) adjusting the mirrors (M1 to M6);

c) processing an area of the correction mirror with a processing beam (65), whereby the form of the correction mirror (M2, M3) changes permanently, and wherein the processing beam (65) impinges on none of the other plurality of mirrors before it processes the correction mirror;

wherein between steps b) and c) no mirrors are removed from the lens.

12. Method according to Claim 11, wherein a processing head (44), which emits the processing beam, is moved across

the area of the correction mirror (M2, M3) during step c) such that the distance (d) between the processing head and the area does not exceed a maximum processing distance of 10 mm during a processing of the correction mirror with the processing beam.

5

13. Method according to Claim 11 or 12, wherein the processing head (44) is situated in the lens (26) only during a processing.

10

14. Method according to Claim 11 or 12, wherein the processing head (44) is introduced into the lens through an access channel (70) before processing, said access channel being provided in a support structure (47) configured to support the mirrors (M1 to M6).

15

15. Method according to any of Claims 12 to 14, wherein the position of the processing head (44) relative to the correction mirror (M2, M3) is detected during processing.

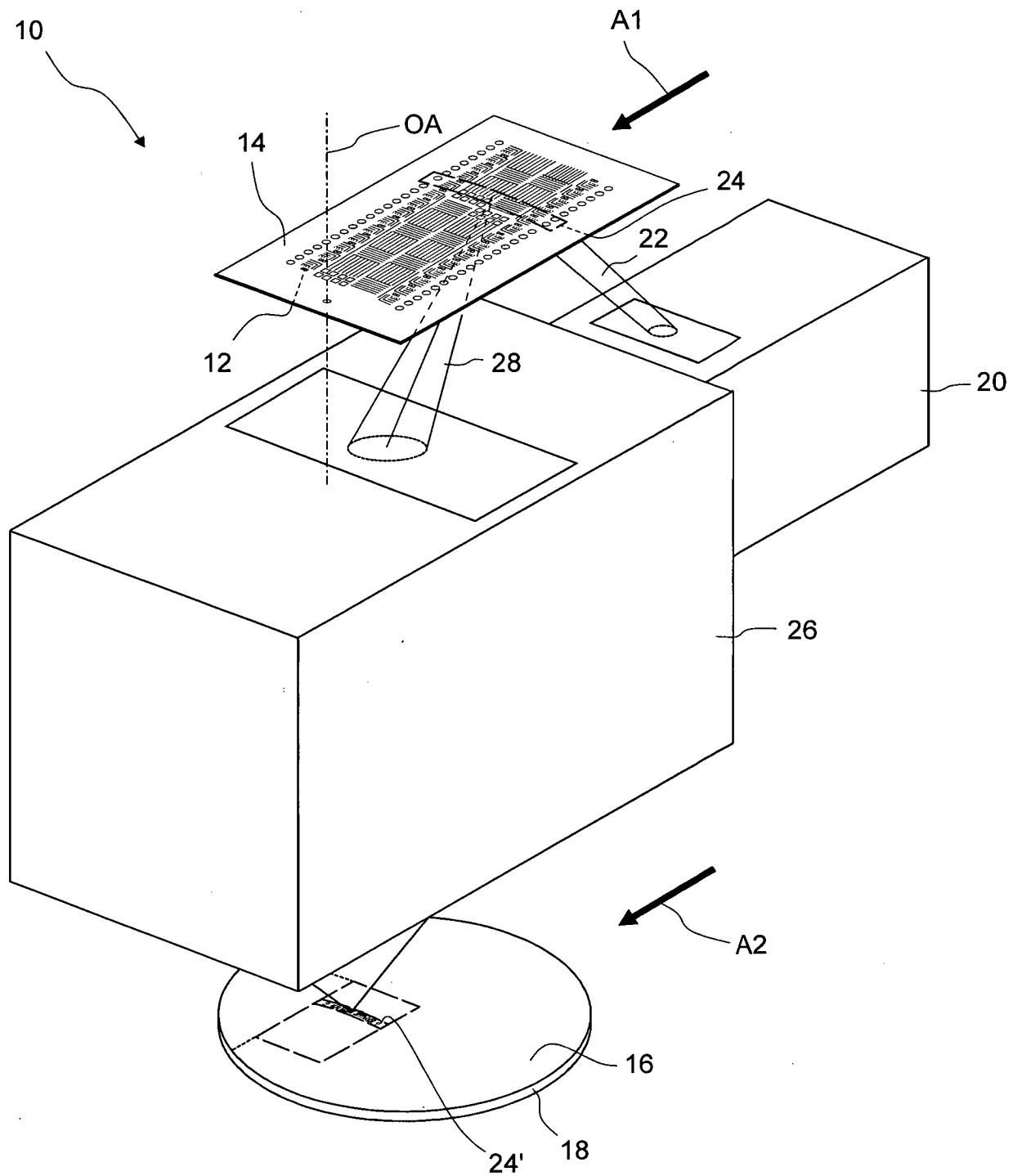


Fig. 1

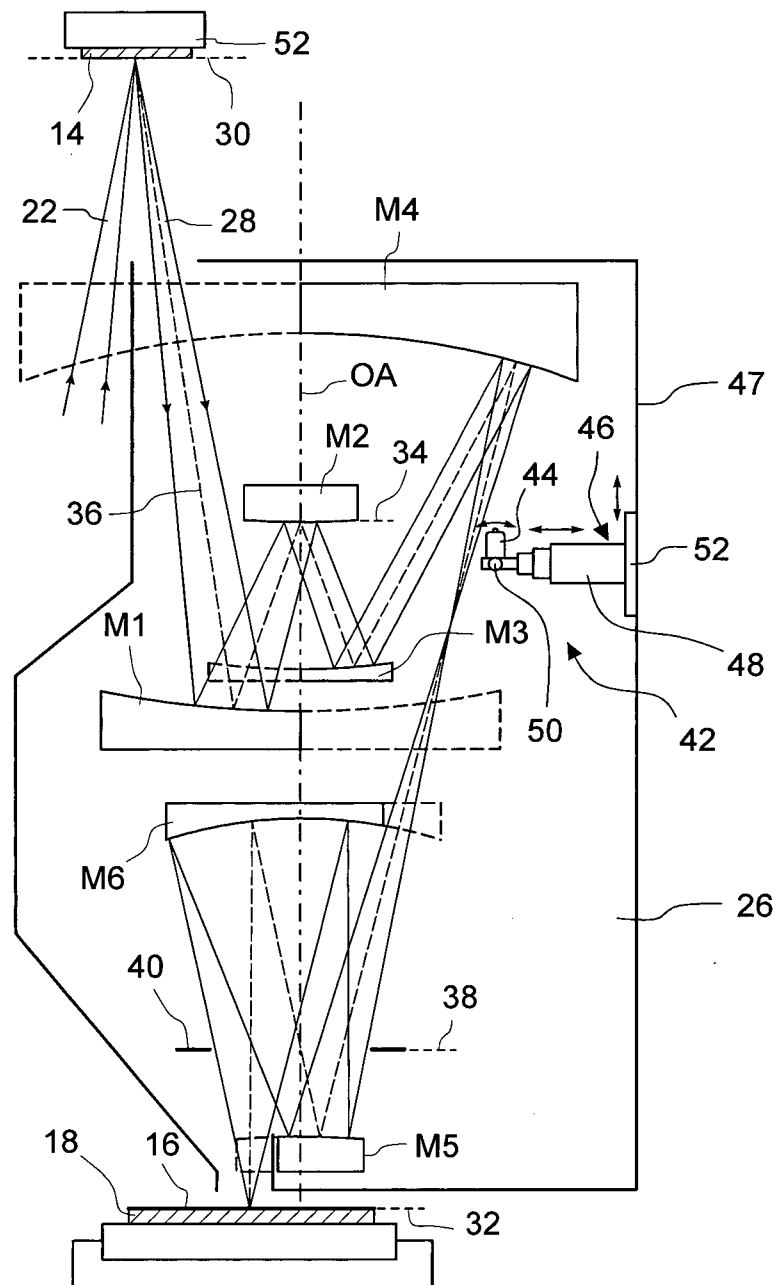


Fig. 2

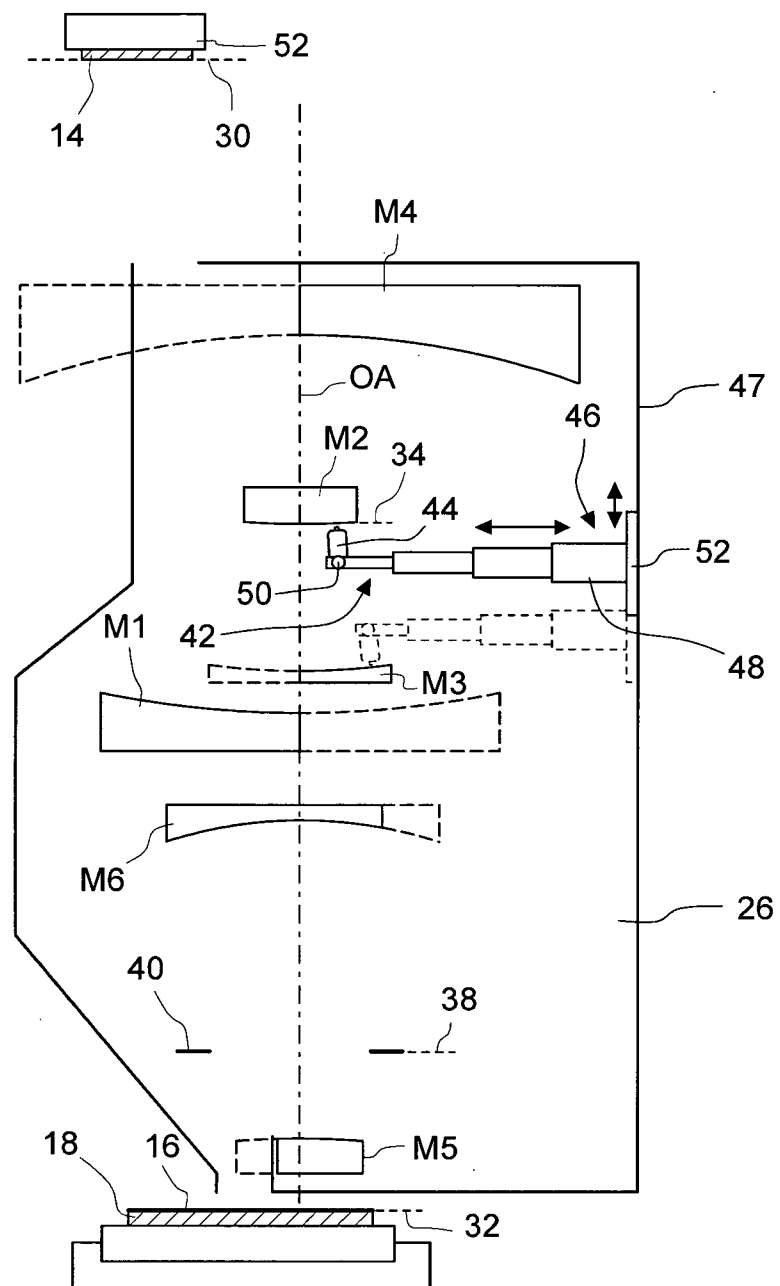


Fig. 3

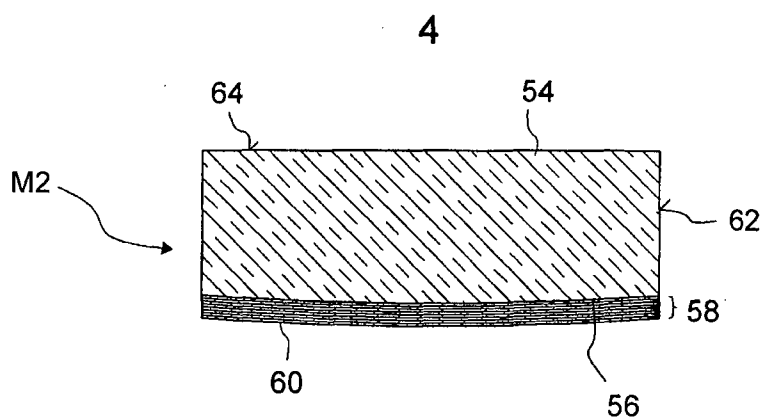


Fig. 4a

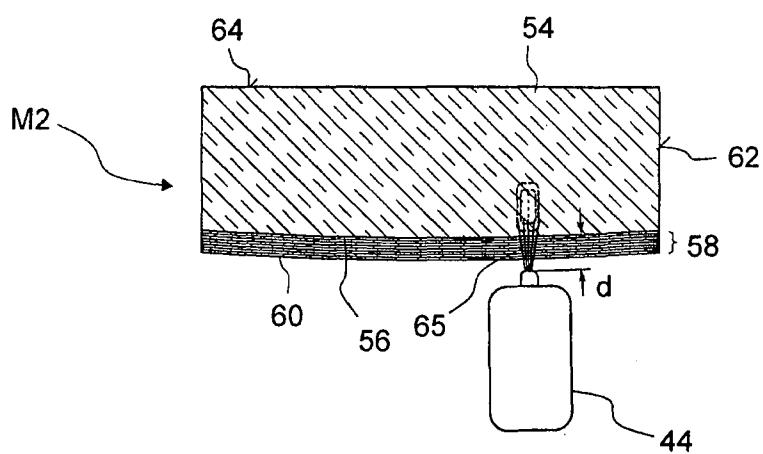


Fig. 4b

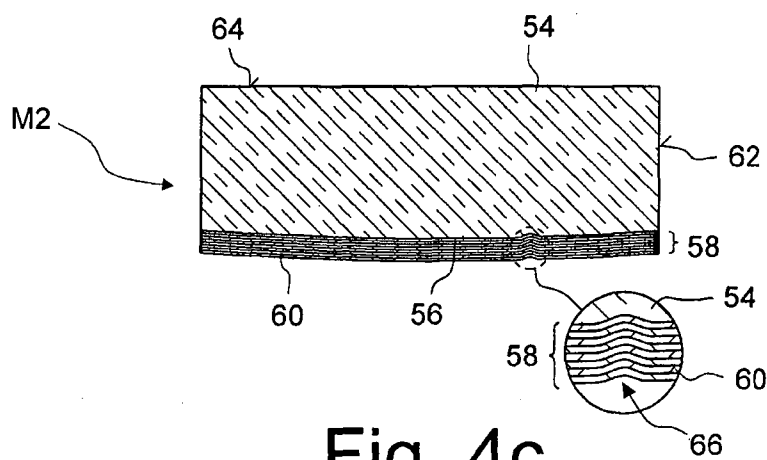


Fig. 4c

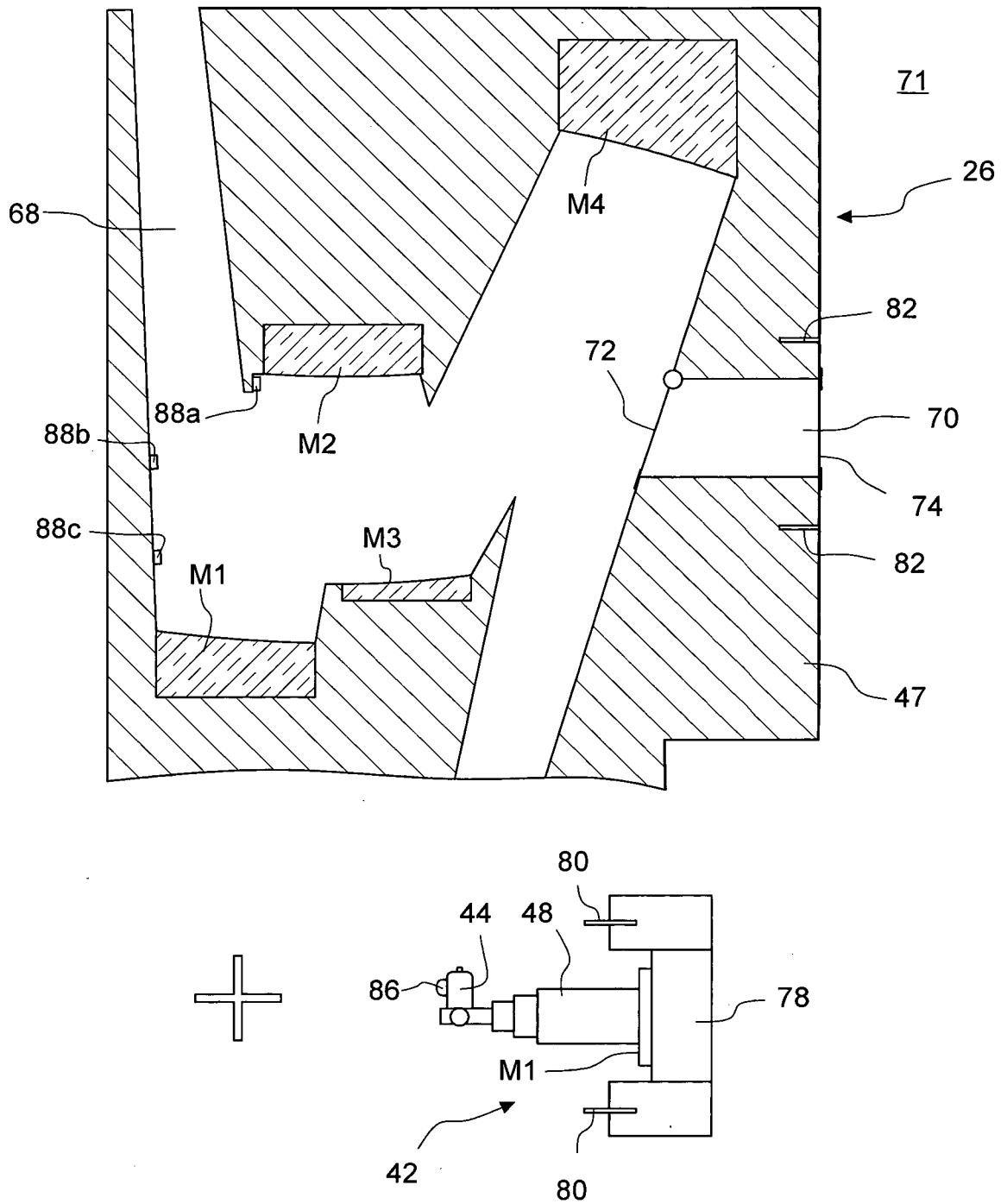


Fig. 5

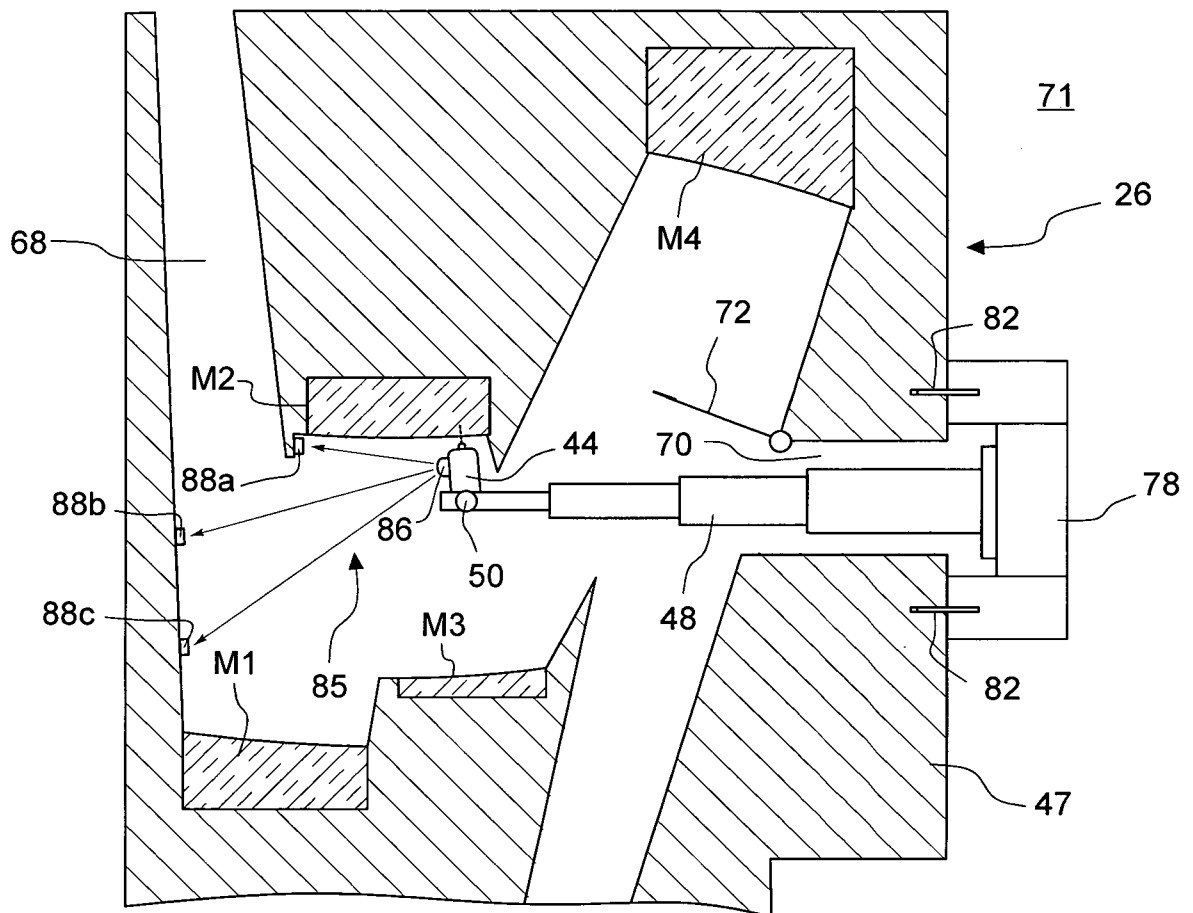


Fig. 6

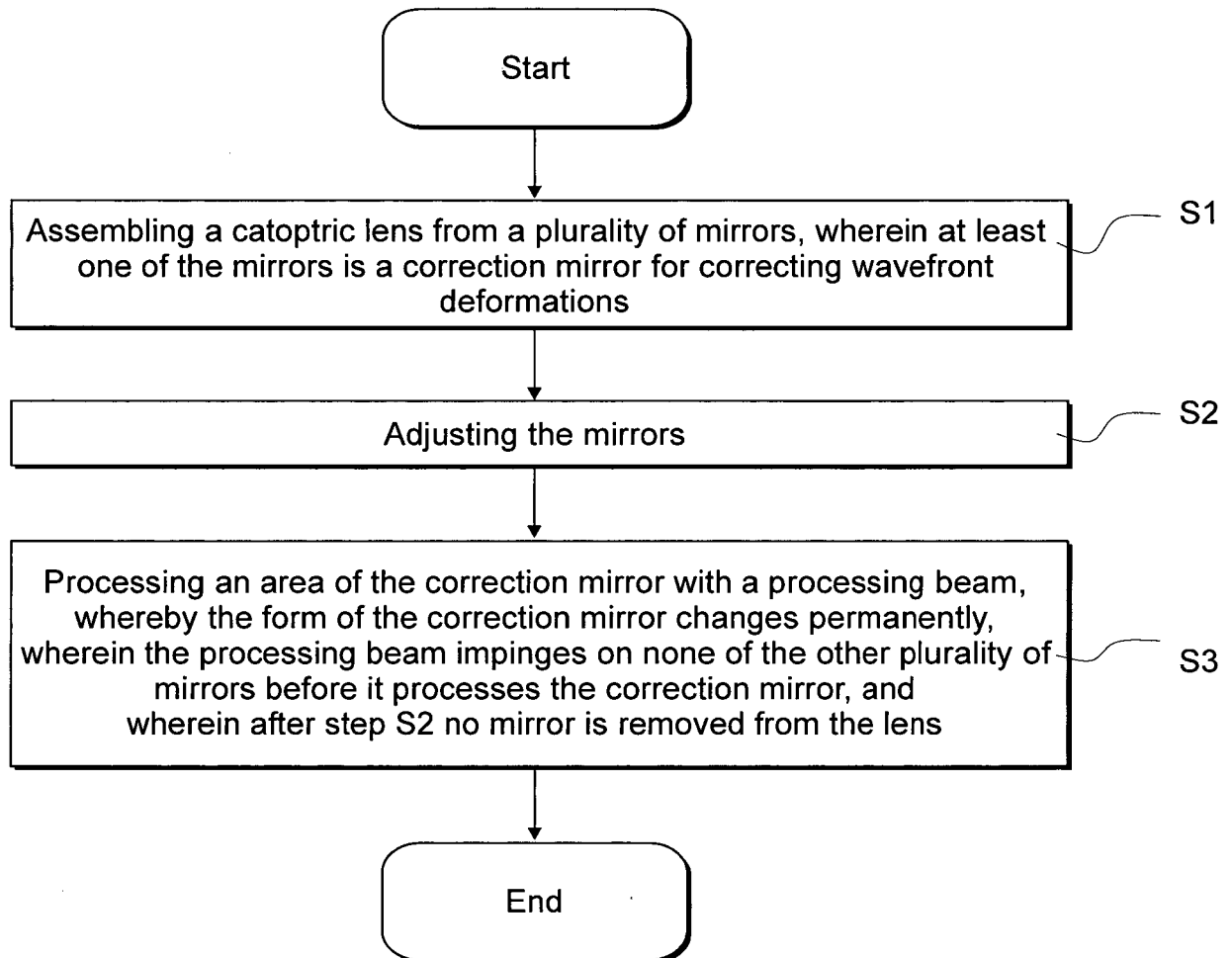


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/001962

A. CLASSIFICATION OF SUBJECT MATTER

INV. G21K1/06 G03F7/20 G02B5/08
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)

G21K G03F G02B

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, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/271957 A1 (MIYACHI TAKESHI [JP] ET AL) 8 December 2005 (2005-12-08) paragraphs [0163] - [0167], [0176] - [0182]; figure 2	1-15
Y	US 2011/279799 A1 (SINGER WOLFGANG [DE] ET AL) 17 November 2011 (2011-11-17) paragraphs [0065] - [0072]; claims 14, 22; figure 1a	1-15
X,P	WO 2013/050199 A1 (ZEISS CARL SMT GMBH [DE]; WEISS MARKUS [DE]; KERWIEN NORBERT [DE]; WEI) 11 April 2013 (2013-04-11) cited in the application pages 12-13; figures 3a-c	1,11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

24 October 2013

Date of mailing of the international search report

08/11/2013

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/001962

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