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(54) Title: METHOD FOR OPERATING A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS

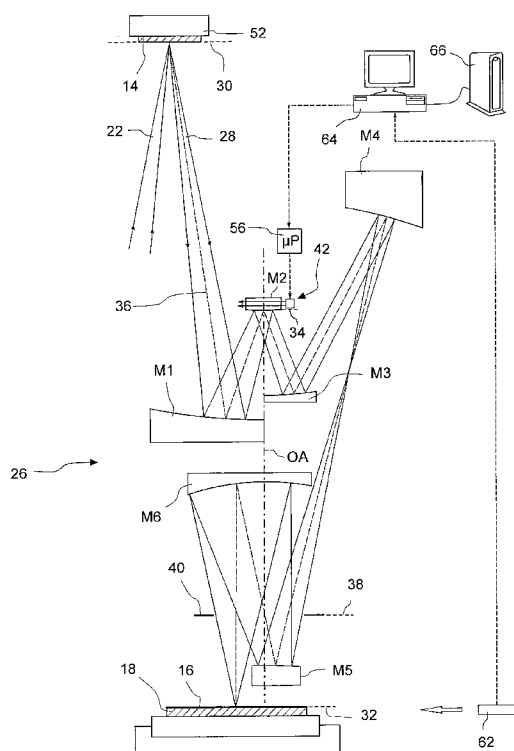


Fig. 2

(57) Abstract: A microlithographic projection exposure apparatus (10) configured in particular for EUV light includes a projection objective (26) having an adaptive mirror (M2) comprising, for its part, a mirror substrate (44) and an actuation unit (42) for deforming the mirror substrate (44). Using imaging aberrations measured previously, a set of control commands for the actuation unit (42) is determined, and when said set of control commands is transferred to the actuation unit (42), the mirror substrate (44) is deformed such that the imaging aberrations measured previously are corrected. Said set of control commands is stored in a nonvolatile data memory (66) and transferred to the actuation unit (42). If the operation of the projection exposure apparatus is interrupted after relatively long operating durations, the correction state previously present can be rapidly reestablished by simply reloading the stored control commands, without a renewed measurement of the imaging aberrations of the projection objective (26) being required.



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METHOD FOR OPERATING A MICROLITHOGRAPHIC
PROJECTION EXPOSURE APPARATUS

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of US provisional application Ser. No. 61/673,778 filed July 20, 2012 and of German patent application 10 2012 212 757.7 filed July 20, 2012. The
5 full disclosure of said German patent application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the invention

The invention relates to a method for operating a microlitho-
10 graphic projection exposure apparatus, and more particularly to an EUV projection exposure apparatus comprising a catop-
tric projection objective containing an adaptive mirror.

2. Description of the prior art

Microlithographic projection exposure apparatuses are used to
15 transfer structures contained in a mask or formed thereon to a photoresist or some other light-sensitive layer. The most
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 di-
20 rects it onto the mask, and a projection objective, which
images that section of the mask which is illuminated by the
illumination system 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 having a center wavelength of 13.5 nm which is in the extreme ultraviolet spectral range (EUV). 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 lenses and other refractive optical elements that are customary at longer wavelengths are replaced by mirrors, and the mask, too, therefore contains a pattern of reflective structures. Projection objectives containing exclusively mirrors as imaging optical elements are referred to as catoptric objectives.

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 objective. Nevertheless, owing to manufacturing and mounting tolerances, the minimum imaging aberrations governed by the optical design are never quite reached. Consequently, even before the initial start-up of the projection exposure apparatus there is generally a permanent need for correction in order to compensate for the imaging aberrations caused by manufacturing and mounting tolerances.

Imaging aberrations of projection objectives are often described as a deviation of a usually measured real optical wavefront from an ideal optical wavefront. Such deviations, also designated as wavefront deformations, can be decomposed into individual portions as a series expansion. A decomposition into Zernike polynomials has proved to be particularly 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, before the start-up of the projection exposure apparatus, the mirrors contained in the projection objectives 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 permanent need for correction can also arise after the initial 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.

Moreover, there are temporary imaging aberrations which occur only in the course of the operation of the projection exposure apparatus and occasionally are dependent on the operating conditions, for example the mask to be imaged and the illumination setting used. One important cause of such temporary imaging aberrations is that the mirrors absorb a part of the high-energy projection light, thereby heat up locally and deform on account of the inhomogeneous temperature distribution resulting therefrom. These thermally governed imaging aberrations subside again when operation is interrupted. Therefore, there is often a need to be able to flexibly correct imaging aberrations of the projection objective also during the operation of the projection exposure apparatus.

One approach for permanently correcting both short-wave and long-wave wavefront deformations consists in locally removing a portion of the surface on suitable mirrors in order in this way 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 lenses, is problematic, however, for a number of reasons in the case of EUV projection objectives. Firstly, although a material removal changes the
5 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
10 itself, as is known from US 2005/0134980 A1.

Another approach is not to remove material from the mirror surface, but to compact the mirror substrate locally below the reflective coating, as is described in
DE 10 2011 084 117 A. For this purpose, a processing beam,
15 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
20 contraction of the substrate finally brings about the desired deformation of the mirror.

In both solution approaches the fundamental problem remains, however, that any type of postprocessing initially requires the incorporation of the mirror into the projection objectives, in order to determine the need for correction and the
25 required postprocessing. If the relevant mirror is then demounted from the projection objective, postprocessed 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
30 itself might therefore be said to act like a 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.

Wavefront deformations in EUV projection objectives can be corrected, however, not only by means of a permanent local material removal at the mirror surfaces, but also with the aid of adaptive mirrors. As is evident from US 6,989,922 B2, for instance, such adaptive mirrors can be used both for correcting temporary imaging aberrations, such as are caused by the partial absorption of EUV light, and for correcting permanent imaging aberrations attributed to manufacturing and mounting tolerances.

Before the adaptive mirror is deformed, the need for correction of the objective has to be determined. In general, this is done by measuring the wavefront in the image plane of the objective with the aid of measuring devices known per se. For such a measurement, however, the operation of the projection exposure apparatus has to be interrupted, which reduces the throughput thereof. If the adaptive mirror is intended also to correct permanent imaging aberrations such as arise as a result of mounting and manufacturing tolerances, then a measurement of the imaging aberrations is thus necessary before each start-up of the projection exposure apparatus. Only then is it possible to calculate how the inductive mirror has to be deformed in order to correct the measured imaging aberrations.

SUMMARY OF THE INVENTION

It is an object of the invention to specify a method for operating a microlithographic projection exposure apparatus with which the throughput thereof can be increased.

This object is achieved according to the invention by means of a method comprising the following steps:

- a) providing a microlithographic projection exposure apparatus comprising a projection objective configured to image a mask onto a light-sensitive layer, wherein the

projection objective contains an adaptive mirror comprising

- a mirror substrate,
- a reflective coating carried by the mirror substrate, and
- an actuation unit which is configured to deform the mirror substrate;

b) measuring the imaging aberrations of the projection objective;

10 c) by using the imaging aberrations measured in step b), determining a set of control commands for the actuation unit in such a way that when the control commands are transferred to the actuation unit, the mirror substrate deforms such that the imaging aberrations measured in
15 step b) change;

d) storing the set of control commands determined in step c) in a nonvolatile data memory;

(e) transferring the control commands stored in step d) to the actuation unit and deforming the mirror substrate
20 with the aid of the actuation unit;

(f) operating the projection exposure apparatus over an uninterrupted operating period of at least one hour;

(g) interrupting the operation of the projection exposure apparatus for at least one hour;

25 (h) repeating steps e) to g) at least once using the set of control commands stored in step d).

In the method according to the invention, therefore, the imaging aberrations of the projection objective are not measured anew after every relatively long interruption of operation in order to calculate the control commands for the actuation unit of the adaptive mirror from the measurement re-
30

sults. Instead, the imaging aberrations are measured only infrequently or even only once, namely before the first start-up of the projection exposure apparatus. The control commands for the actuation unit determined on the basis of this measurement are stored in a nonvolatile data memory, such that they can be read out after every relatively long interruption of operation and can be transferred to the actuation unit of the adaptive mirror.

In this way, the adaptive mirror performs the function of mirrors which in the prior art are permanently postprocessed by material removal for correcting imaging aberrations caused by manufacturing and mounting tolerances. The problems associated with the local postprocessing of mirror surfaces, as outlined thoroughly further above, are avoided by virtue of the operating method according to the invention. Instead, before every resumption of operation of the projection exposure apparatus that ensues after an interruption of operation, the mirror substrate is deformed such that the adaptive mirror corrects the permanent imaging aberrations, without a measurement of the imaging aberrations being necessary for this every time.

The adaptive mirror can of course also be used for correcting such imaging aberrations which occur only temporarily during the operation of the projection exposure apparatus. In this case, further control commands have to be communicated to the actuation unit of the adaptive mirror in order that the mirror substrate deforms such that the additional imaging aberrations that occurred are corrected. In contrast to imaging aberrations caused by manufacturing and mounting tolerances, such temporary imaging aberrations can often also be predicted by simulation. The actuation unit can then deform the mirror substrate of the adaptive mirror such that the temporary imaging aberrations determined by simulation are corrected. In this way, it is possible for the projection exposure apparatus to be operated in a manner that completely dispenses with measurements of imaging aberrations during

which the apparatus cannot be used and which therefore impair the throughput thereof.

As has already been explained further above, permanent imaging aberrations can also change over a relatively long operating duration. This can necessitate repeating steps b) to d), as a result of which a new set of control commands is stored in the data memory before steps e) to h) are carried out again. The measurement of the imaging aberrations and the determination of new control commands for the actuation unit of the adaptive mirror are then effected only at relatively long time intervals of typically several weeks or even several months.

Triggers for a further measurement of the imaging aberrations and a new determination of the control commands may be either the elapsing of a predefined operation period, e.g. a period of between two and six months, or an indication of the deterioration of the imaging properties. Such indications can result from a short measurement, as described in US 6,989,922 B2 already cited in the introduction, or can be the result of quality inspections of the components which are produced using the projection exposure apparatus.

Insofar as hitherto mention has been made of the correction of imaging aberrations, it should be pointed out that the adaptive mirror generally need not necessarily bring about a correction of the imaging aberrations, but rather can, under certain circumstances, merely bring about a change in the imaging aberrations. This is because it often suffices to convert specific imaging aberrations into other imaging aberrations, which can then be corrected relatively easily by other measures, e.g. a displacement of entire mirrors with the aid of manipulators. In relation to wavefront deformations, this means, for example, that a relatively weak, but nevertheless disturbing short-wave wavefront deformation can be converted into a relatively strong long-wave wavefront deformation, which, however, can easily be corrected by other measures.

In many cases, however, the set of control commands for the actuation unit will be defined in such a way that at least one image aberrations or a rounded mean value over all the imaging aberrations measured in step b) decreases.

- 5 The invention is preferably applicable in particular in catoptric objectives of EUV projection exposure apparatuses designed for projection light having a center wavelength of between 5 nm and 30 nm. In principle, however, the invention can also be applied to projection exposure apparatuses de-
10 signed for longer wavelengths in the DUV or VUV spectral range.

It is particularly advantageous if the actuation unit generates a variable temperature distribution in the mirror substrate. Such a variable temperature distribution is trans-
15 lated into a variable shape of the mirror substrate, without forces having to be exerted on the adaptive mirror externally for this purpose. In order to generate the variable temperature distribution, the actuation unit may contain a plurality of individually drivable heating light sources that each di-
20 rect a heating light beam onto the mirror substrate, said beam being at least partly absorbed therein. Actuation units of this type are known per se and described in
DE 100 00 191 A1.

It goes without saying that the deformation of the mirror
25 substrate can also be produced with the aid of other types of actuation units, such as are described for example in
US 6,989,922 B2, cited above, US 7,572,019 B2 or
UA 6,880,942 B2.

The term "deformation" is to be construed broadly in the pre-
30 sent context and comprises all changes of the adaptive mirror that are capable of affecting the phase of an incident optical wavefront. In addition to a deformation as such this comprises, for example, refractive index variations that are produced in a reflective coating.

BRIEF DESCRIPTION OF THE DRAWINGS

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

- 5 Figure 1 is a schematic perspective view of an EUV projection exposure apparatus according to the invention;
- Figure 2 is a meridional section through the projection objective of the projection exposure apparatus shown in Figure 1;
- 10 Figure 3 is a bottom view of an adaptive0 mirror contained in the projection objective shown in Figure 2;
- Figure 4 is a meridional section through the adaptive mirror shown in Figure 3; and
- Figure 5 is a flow chart listing important steps of the
15 method according to the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

1. Basic construction

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
20 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
30 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 center 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 catoptric projection objective 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 projection objective 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 projection objective 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 projection objective 26. In the exemplary embodiment illustrated, the image 24' generated by the projection objective 26 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 emerge from each point in the illumination field 24 which is situated in an object plane of the projection objective 26, said light beams entering into the projection objective 26. The latter has the effect that the entering

light beams converge in an image plane of the projection objective 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 referred to as optical conjugation.

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 projection objective 26 is a measure of the numerical aperture NA thereof. On account of the reduced imaging, the image-side numerical aperture NA of the projection objective 26 is enlarged by the reciprocal of the imaging scale β .

Figure 2 shows important components of the projection objective 26 likewise schematically and not to scale in a meridional section. Between the object plane indicated by 30 and the image plane indicated by 32, a total of six mirrors M1 to M6 are arranged along an optical axis OA. The light beam 28 emerging 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, which is embodied as an adaptive mirror, impinges on a concave third mirror M3, is reflected 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 an image point in the image plane 32 which is optically conjugate with respect to the object point in the object plane 30.

The projection objective 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. Adaptive mirror

The adaptive mirror M2 comprises a mirror substrate, a reflective coating carried thereby, and an actuation unit 42 that is configured to deform the mirror substrate in a targeted manner. The construction of the adaptive mirror M2 is explained in greater detail below with reference to Figures 3 and 4, which show the adaptive mirror M2 in a bottom view and, respectively, a section along the line IV-IV.

The mirror substrate designated by 44 consists of a material which has, at the operating temperature of the mirror M2, a coefficient of thermal expansion that differs from zero. The mirror substrate 44 therefore deforms if its spatial temperature distribution changes. By way of example, quartz glass or ULE® is suitable as material for the mirror substrate 44.

A reflective coating 48 is applied to a precisely processed optical surface 46 of the mirror substrate 44, said reflective coating being illustrated with an exaggerated thickness in Figure 4 and constituting an arrangement of a plurality of thin double layers. The reflective coating 48 is designed such that the proportion of the incident short-wave EUV light that is reflected is as high as possible and it is reflected over a relatively large angular range.

The actuation unit 42 comprises a total of six heating units 50, which are arranged in two mutually parallel planes in the embodiment illustrated. In this case, three heating units 50 are arranged in each plane, said heating units having an

identical construction and being distributed uniformly around a cylindrical circumferential surface 52 of the mirror substrate 44, such that adjacent heating units 50 within each plane form an angle of 120° in each case.

5 Each heating unit 50 contains nine heating light sources 54, which can be e.g. laser diodes. Each heating light source 54 is designed for directing a heating light beam 56 onto the cylindrical circumferential surface 52 of the mirror substrate 54. As can best be discerned in the bottom view in
10 Figure 3, the heating light beams 56 are refracted at the cylindrical circumferential surface 52 if they are not incident thereon perpendicularly, and penetrate into the mirror substrate 44. The heating light sources 54 are arranged in the heating units 50 such that a maximum of 9 heating light
15 beams 56 leave the heating units 50 in a fan-like manner.

The heating light beams 54 passing through the mirror substrate 44 in a fan-like manner overlap within a central volume of the mirror substrate 44, said volume being indicated by a dashed circle 60 in Figure 3. In this way, the central
20 volume can be subjected to the heating light beams 54 uniformly densely and from different sides.

As a result of partial absorption, the heating light beams 56 lose part of their energy and locally heat the mirror substrate 44 as a result. Since the heating light sources 54 can
25 be driven individually by a control device 56 indicated in Figure 2, it is possible to generate different temperature distributions in the mirror substrate 44. Owing to the arrangement of the heating units 50 in two parallel planes (cf. Figure 4), in this case the temperature distribution can be
30 varied in a targeted manner in all three spatial directions.

These temperature distributions lead to the already mentioned deformation of the mirror substrate 44 and of the reflective coating 48 carried thereby. It is possible to produce both
35 long-wave distortions, such as are required for instance in astigmatism correction, and short-wave deformations, such as

are typically required for correcting imaging aberrations caused by material and manufacturing tolerances.

3. *Function*

When the projection objective 26 is initially assembled, the
5 mirrors M1 to M6 are oriented carefully with respect to one another, which is usually carried out with simultaneous measurement of the wavefront in the image plane 32. For this purpose, a wavefront measuring device indicated by 62 in Figure 2 is moved into the image plane 32 into the image field
10 of the projection objective 26. The adjustment is then carried out until significant correction of the wavefront can no longer be obtained.

Usually, however, residual imaging aberrations remain even after very careful adjustment of the mirrors M1 to M6, and
15 said residual imaging aberrations may be so great that they can no longer be afforded tolerance. Therefore, after the mounting of the projection objective 26, the wavefront is measured again with the aid of the wavefront measuring device 62. The measurement results are transferred from the wave-
20 front measuring device 62 to a computer 64, which calculates the residual correction requirement. The computer 64 additionally determines a set of control commands for the actuation unit 42 of the adaptive mirror M2. In this case, the control commands are defined such that when the control com-
25 mands are transferred to the actuation unit 42, the mirror substrate 44 deforms in such a way that the imaging aberrations measured previously are at least partly corrected or at least converted into imaging aberrations that can be corrected in some other way, e.g. by changing the position of
30 individual mirrors M1 to M6 with the aid of manipulators. The set of control commands determined by the computer 64 is stored in a nonvolatile data memory 66, such that it can be retrieved again even after an interruption of projection operation and preferably even after an interruption of the
35 power supply.

In a next step, the control commands determined by the computer 64 and stored in the data memory 66 are transferred to the actuation unit 42, as a result of which the mirror substrate 44 deforms and the adaptive mirror M2 manifests its
5 correction effect.

The projection exposure apparatus 10 is subsequently operated over a relatively long uninterrupted operating period in order to transfer the pattern comprising structures 12, said pattern being contained in the mask 14, to the substrates 18
10 and to produce microstructured components in this way.

After relatively long uninterrupted operation, which may have a duration of several days or even weeks, it is generally unavoidable that the projection exposure apparatus 10 is temporarily shut down. The reason for an interruption of operation may be e.g. maintenance work, replacement of parts subject to wear, disturbances or equipment changes. During the
15 interruption of operation, the actuation unit 42 of the adaptive mirror M2 is not in operation either, and so the deformation of the mirror substrate 44 previously produced by the actuation unit 42 is lost.
20

According to the invention, upon resumption of operation, the control commands for the actuation unit that are stored in the data memory 66 are fed to the actuation unit 42 again, in order that the adaptive mirror M2 once again establishes its
25 correction effect.

This cycle of operating periods and interruptions of operation can be repeated over months or even years, without necessitating a further measurement of imaging aberrations of the projection objective 26 with the aid of the wavefront
30 measuring device 62.

During the operation of the projection exposure apparatus 10, however, temporary imaging aberrations can occur which arise for example as a result of the absorption of the high-energy EUV light in the mirror substrates of the mirrors M1 to M6.
35 In principle, such imaging aberrations can be detected by the

wavefront measuring device 62 in a short interruption of operation. The computer 64 then modifies the control commands transferred to the actuation unit 42 such that the additional temporary imaging aberrations are also corrected by the adaptive mirror M2.

A measurement of the imaging aberrations with the aid of the wavefront measuring device 62 can be dispensed with, however, if the temporary imaging aberrations are determined by simulation. In this case, the adaptive mirror M2 is readjusted in order to correct the temporary imaging aberrations determined by simulation or at least to change them such that they can be corrected more easily by other measures.

After relatively long operating durations, the imaging properties of the projection objective 26 can also deteriorate permanently. This can be caused for example by irreversible and locally delimited compactions of parts of the mirror substrates which are caused by the high-energy EUV light.

In this case, the most expedient procedure is to measure the imaging aberrations anew again with the aid of the wavefront measuring device 62, to instigate the calculation of a new set of control commands for the actuation unit 42 by the computer 64 and then to deform the mirror substrate 44 of the adaptive mirror M2 in accordance with the new set of control commands. Such renewed measurements of the imaging aberrations with the aid of the wavefront measuring device 42 can be carried out for example after predefined operating periods have elapsed, or only when indications of a deterioration in the imaging properties are present. Said indications may be e.g. an increase in the rejects of the microstructured components produced by the projection exposure apparatus 10.

4. *Important method steps*

Important steps of the method according to the invention are summarized in a flow chart shown in Figure 5.

A first step S1 involves providing a microlithographic projection exposure apparatus having a projection objective containing an adaptive mirror comprising a mirror substrate and an actuation unit.

- 5 A second step S2 involves measuring imaging aberrations of the projection objective.

- A third step S3 involves determining a set of control commands in such a way that when the control commands are transferred to the actuation unit, the mirror substrate is de-
10 formed such that the imaging aberrations measured in step S2 are corrected.

A fourth step S4 involves storing the set of control commands determined in step S3.

- A fifth step S5 involves transferring the stored control com-
15 mands to the actuation unit, as a result of which the mirror substrate deforms with the aid of the actuation unit.

A sixth step S6 involves operating the projection exposure apparatus by transferring a pattern contained in a mask to a light-sensitive layer.

- 20 A seventh step S7 involves interrupting the operation of the projection exposure apparatus for a relatively long period.

An eighth step S8 involves repeating steps S5 to S7 using the set of control commands stored in step S4.

CLAIMS

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1. Method for operating a microlithographic projection exposure apparatus comprising the following steps:
 - a) providing a microlithographic projection exposure apparatus (10) comprising a projection objective (26) configured to image a mask (14) onto a light-sensitive layer (16), wherein the projection objective (26) contains an adaptive mirror (M2) comprising
 - a mirror substrate (44),
 - a reflective coating (48) carried by the mirror substrate (44), and
 - an actuation unit (42) which is configured to deform the mirror substrate (44);
 - b) measuring imaging aberrations of the projection objective (26);
 - c) by using the imaging aberrations measured in step b), determining a set of control commands for the actuation unit (42) in such a way that when the control commands are transferred to the actuation unit (42), the mirror substrate (44) deforms such that the imaging aberrations measured in step b) change;
 - d) storing the set of control commands determined in step c) in a nonvolatile data memory (66);
 - e) transferring the control commands stored in step d) to the actuation unit (42) and deforming the mirror substrate (44) with the aid of the actuation unit (42);

- f) operating the projection exposure apparatus (10) over an uninterrupted operating period of at least one hour;
- g) interrupting the operation of the projection exposure apparatus (10) for at least one hour;
- h) repeating steps e) to g) at least once using the set of control commands stored in step d).
2. Method according to Claim 1, wherein temporary imaging aberrations are determined by simulation, and wherein the actuation unit (42) deforms the mirror substrate (44) of the adaptive mirror (M2) such that the temporary imaging aberrations are changed.
3. Method according to Claim 1 or 2, wherein steps b) to d) are repeated after step h), as a result of which a new set of control commands is stored in the data memory (66) before steps e) to h) are carried out again.
4. Method according to Claim 3, wherein steps b) to d) are repeated only after either a predefined operating period has elapsed or indications of a deterioration of the imaging properties are present.
5. Method according to any of the preceding claims, wherein, when the control commands are transferred to the actuation unit (42), the adaptive mirror (M2) deforms such that at least one of the imaging aberrations measured in step b) decreases.
6. Method according to Claim 5, wherein, when the control commands are transferred to the actuation unit (42), the adaptive mirror (M2) deforms such a round mean value over all of the imaging aberrations measured in step b) decreases.
7. Method according to any of the preceding claims, wherein the actuation unit (42) generates a variable temperature distribution in the mirror substrate (44).

8. Method according to Claim 7, wherein the actuation unit (42) contains a plurality of individually drivable heating light sources (54) which each direct a heating light beam (56) onto the mirror substrate (44), said heating light beam being at least partly absorbed therein.
9. Method according to any of the preceding claims, wherein the projection objective (26) is a catoptric objective.
10. Method according to any of the preceding claims, wherein the projection exposure apparatus is designed for projection light having a center wavelength between 5 nm and 30 nm.

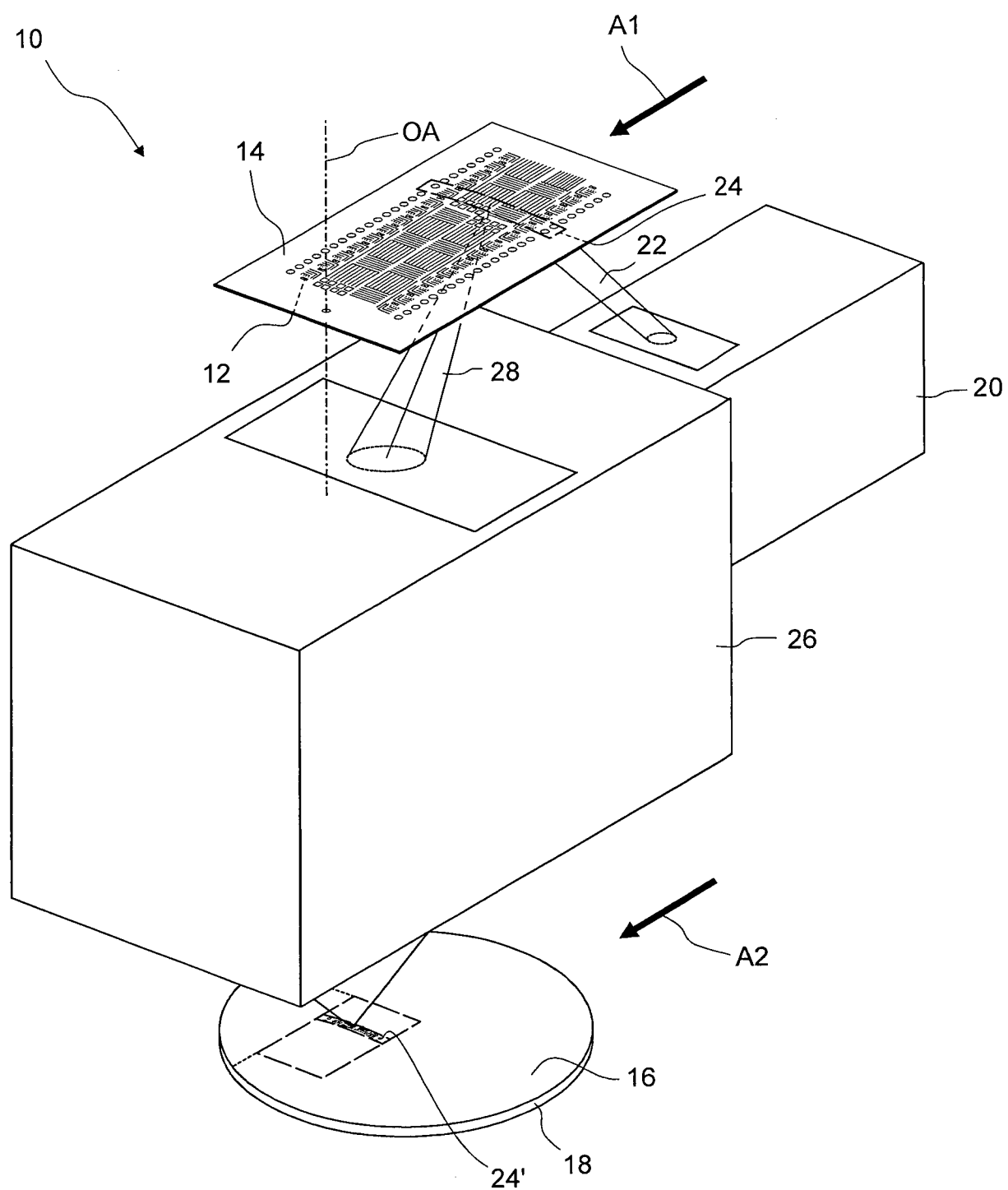


Fig. 1

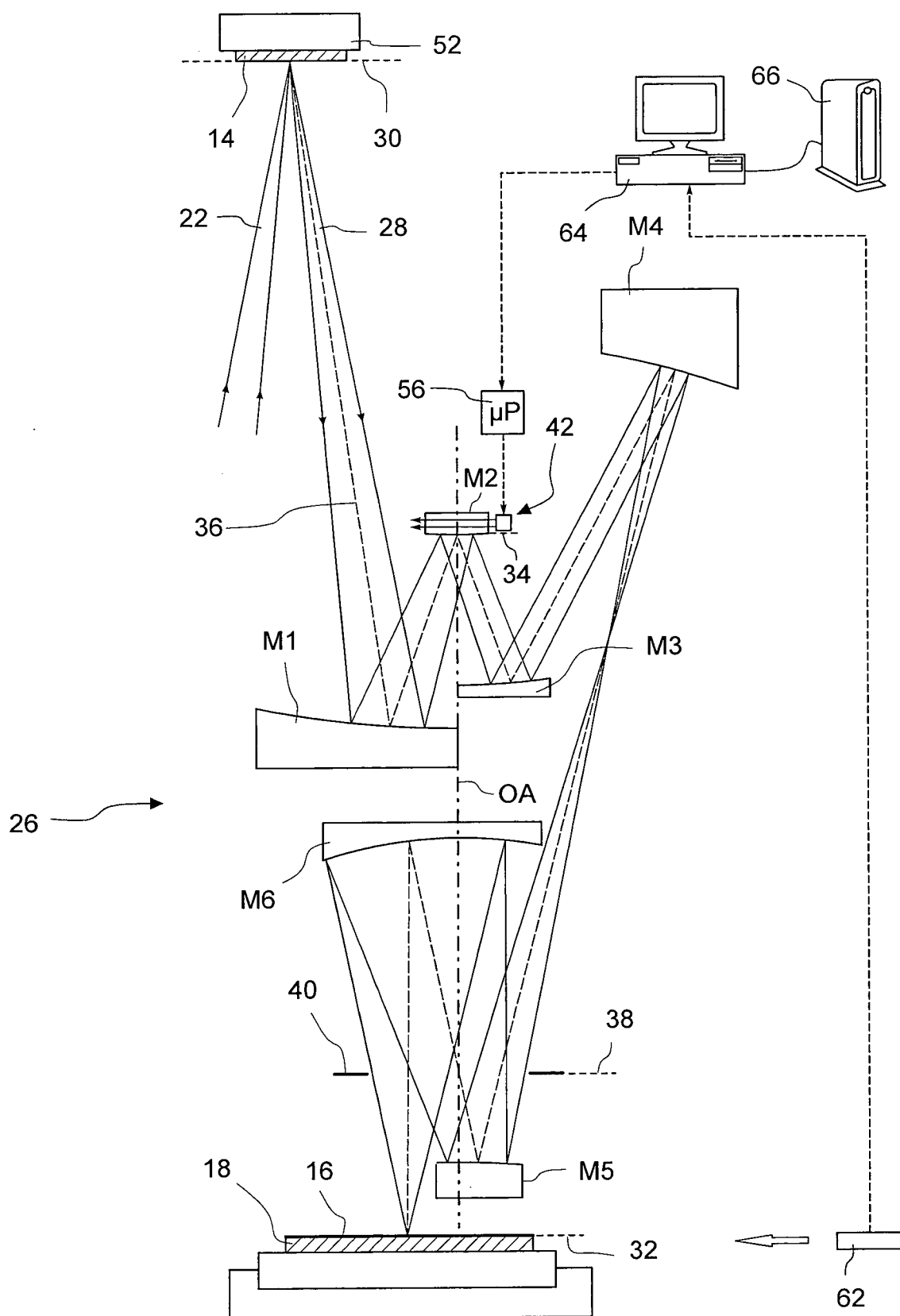


Fig. 2

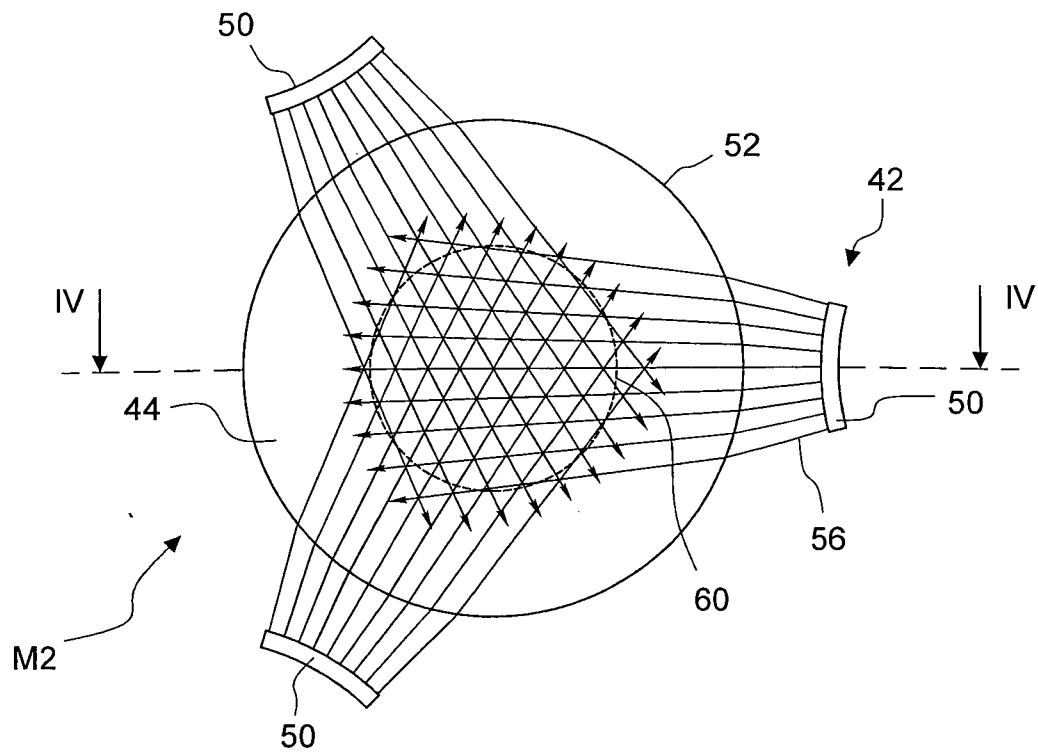


Fig. 3

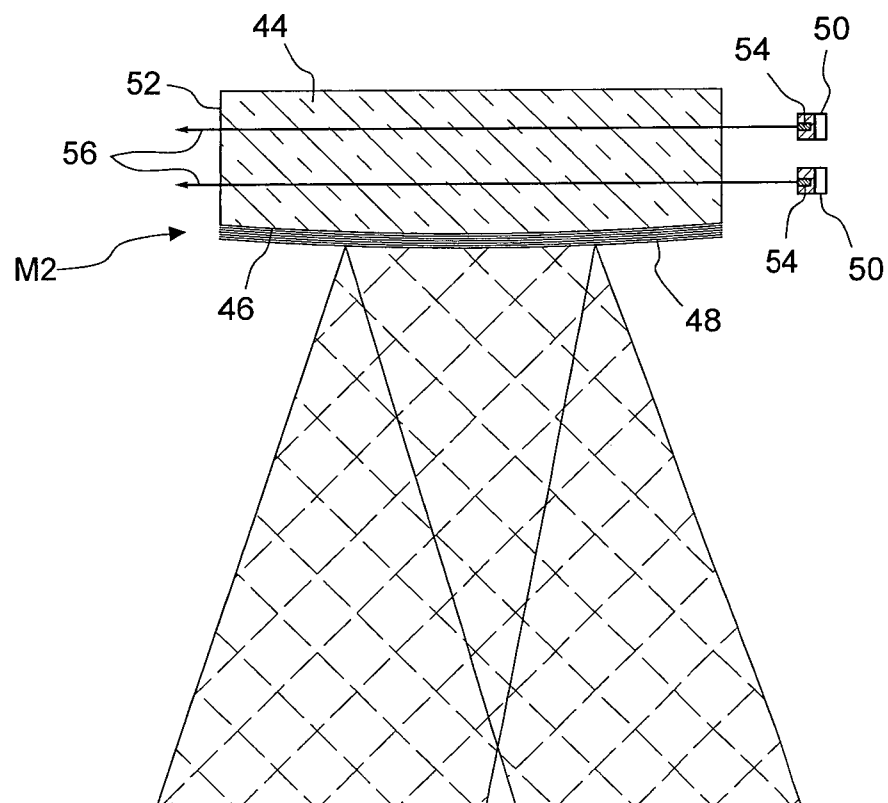


Fig. 4

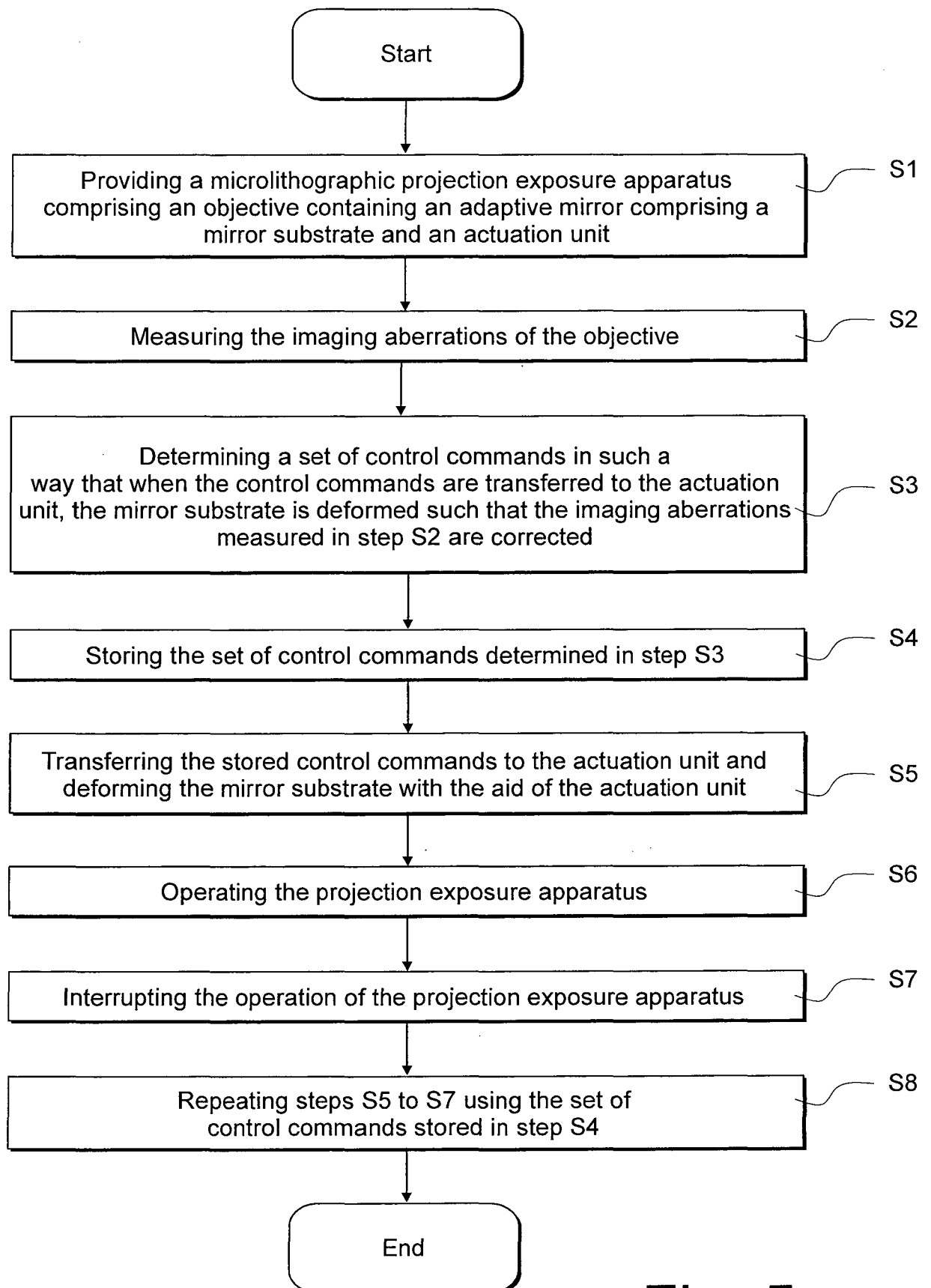


Fig. 5