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

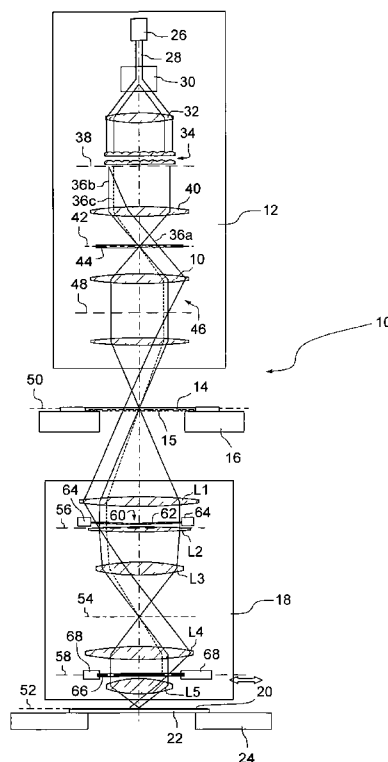


Fig. 1

(57) Abstract: A method of operating a microlithographic projection exposure apparatus comprising the steps of : providing an illumination system (12) having an illumination pupil plane (38); providing a projection objective (18) having an objective pupil plane (58), which is optically conjugate to the illumination pupil plane (38); providing a mask (14) containing structures (15); determining a target spatial irradiance distribution of projection light (28) in the illumination pupil plane (38); illuminating a portion of the mask (14) with projection light that produces in the illumination pupil plane (38) a modified spatial irradiance distribution, wherein there is an excess area (70) in the illumination pupil plane which is irradiated in the modified spatial irradiance distribution, but is not irradiated in the target spatial irradiance distribution; and stopping those light rays (36c), which pass the excess area (70) in the illumination pupil plane (38), from reaching a light sensitive surface (20) by using a stop (66; 166; 266) that is arranged in the projection pupil plane (58).



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METHOD OF OPERATING A
MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS
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BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention generally relates to microlithographic projection exposure apparatus. Such apparatus are used for the production of large-scale integrated circuits and other microstructured components. The invention relates in particular to a method of operating such an apparatus so that aberrations caused by lens heating effects can be more easily corrected.

2. Description of Related Art

10 Microlithography (also called photolithography or simply lithography) is a technology for the fabrication of integrated circuits, liquid crystal displays and other microstructured devices. The process of microlithography, in conjunction with the process of etching, is used to pattern features in thin film stacks that have been formed on a substrate, for example a silicon wafer. At each layer of the fabrication, the wafer is first coated with a photoresist which is a material that is sensitive to radiation, such as deep ultraviolet (DUV), vacuum ultraviolet (VUV) or extreme ultraviolet (EUV) light.

20 Next, the wafer with the photoresist on top is exposed to projection light through a mask in a projection exposure apparatus. The mask contains a circuit pattern to be projected onto the photoresist. After exposure the photoresist is developed to produce an image corresponding to the circuit pattern contained in the mask. Then an etch process transfers the circuit pattern into the thin film stacks on the wafer. Finally, the photoresist is removed. Repetition of this process with different masks results in a multi-layered microstructured component.

25

A projection exposure apparatus typically includes an illumination system, a mask alignment stage for aligning the mask, a projection objective and a wafer alignment stage for aligning the wafer coated with the photoresist. The illumination
5 system illuminates a field on the mask that may have the shape of a rectangular slit or a narrow ring segment, for example.

In current projection exposure apparatus a distinction can be made between two different types of apparatus. In one type
10 each target portion on the wafer is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In the other type of apparatus, which is commonly referred to as a step-and-scan apparatus or simply scanner, each target
15 portion is irradiated by progressively scanning the mask pattern under the projection light beam in a given reference direction while synchronously scanning the substrate parallel or anti-parallel to this direction. The ratio of the velocity of the wafer and the velocity of the mask is equal to the
20 magnification β of the projection lens, which is usually smaller than 1, for example $\beta = 1/4$.

It is to be understood that the term "mask" (or reticle) is to be interpreted broadly as a patterning means. Commonly used masks contain transmissive or reflective patterns and
25 may be of the binary, alternating phase-shift, attenuated phase-shift or various hybrid mask type, for example.

One of the essential aims in the development of projection exposure apparatus is to be able to lithographically produce structures with smaller and smaller dimensions on the wafer.
30 Small structures lead to high integration densities, which generally has a favorable effect on the performance of the microstructured components produced with the aid of such ap-

paratus. Furthermore, the more devices can be produced on a single wafer, the higher is the throughput of the apparatus.

The size of the structures which can be generated depends primarily on the resolution of the projection objective being used. Since the resolution of projection objectives is inversely proportional to the wavelength of the projection light, one way of increasing the resolution is to use projection light with shorter and shorter wavelengths. The shortest wavelengths currently used are 248 nm, 193 nm or 157 nm and thus lie in the deep or vacuum ultraviolet spectral range. Also apparatus using EUV light having a wavelength of about 13 nm are meanwhile commercially available.

Another way of increasing the resolution is based on the idea of introducing an immersion liquid with a high refractive index into an immersion interspace, which remains between a last lens on the image side of the projection objective and the photoresist or another photosensitive surface to be exposed. Projection objectives which are designed for immersed operation, and which are therefore also referred to as immersion objectives, can achieve numerical apertures of more than 1, for example 1.3 or even higher.

The correction of image errors (i.e. aberrations) is becoming increasingly important for projection objectives with very high resolution. Different types of image errors usually require different correction measures.

The correction of rotationally symmetric image errors is comparatively straightforward. An image error is referred to as being rotationally symmetric if the wavefront deformation in the exit pupil of the projection objective is rotationally symmetric. The term wavefront deformation refers to the deviation of a wave from the ideal aberration-free wave. Rotationally symmetric image errors can be corrected, for exam-

ple, at least partially by moving individual optical elements along the optical axis.

Correction of those image errors which are not rotationally symmetric is more difficult. Such image errors occur, for example, because lenses and other optical elements heat up rotationally asymmetrically. One image error of this type is astigmatism.

A major cause for rotationally asymmetric image errors is a rotationally asymmetric, in particular slit-shaped, illumination of the mask, as is typically encountered in projection exposure apparatus of the scanner type. The slit-shaped illuminated field causes a non-uniform heating of those optical elements that are arranged in the vicinity of field planes. This heating results in deformations of the optical elements and, in the case of lenses and other elements of the refractive type, in changes of their index of refraction. If the materials of refractive optical elements are repeatedly exposed to the high energetic projection light, also permanent material changes are observed. For example, a compaction of the materials exposed to the projection light sometimes occurs, and this compaction results in local and permanent changes of the index of refraction. In the case of mirrors the reflective multi-layer coatings may be damaged by the high local light intensities so that the reflectance is locally altered.

The heat induced deformations, index changes and coating damages alter the optical properties of the optical elements and thus cause image errors. Heat induced image errors sometimes have a twofold symmetry. However, image errors with other symmetries, for example threefold or fivefold, are also frequently observed in projection objectives.

Another major cause for rotationally asymmetric image errors are certain asymmetric illumination settings in which the pu-

pupil plane of the illumination system is illuminated in a rotationally asymmetric manner. Important examples for such settings are dipole settings in which only two poles are illuminated in the pupil plane. With such a dipole setting, also the pupil planes in the projection objective contain two strongly illuminated regions. Consequently, lenses or mirrors arranged in or in the vicinity of such an objective pupil plane are exposed to a rotationally asymmetric intensity distribution which gives rise to rotationally asymmetric image errors. Also quadrupole settings often produce rotationally asymmetric image errors, although to a lesser extent than dipole settings.

In order to correct rotationally asymmetric image errors, US 6,338,823 B1 proposes a lens which can be selectively deformed with the aid of a plurality of actuators distributed along the circumference of the lens. The deformation of the lens is determined such that heat induced image errors are at least partially corrected.

US 7,830,611 B2 discloses a similar correction device. In this device one surface of a deformable plate contacts an index matched liquid. If the plate is deformed, the deformation of the surface adjacent the liquid has virtually no optical effect. Thus this device makes it possible to obtain correcting contributions from the deformation not of two, but of only one optical surface. A partial compensation of the correction effect, as it is observed if two surfaces are deformed simultaneously, is thus prevented.

However, the deformation of optical elements with the help of actuators has also some drawbacks. If the actuators are arranged at the circumference of a plate or a lens, it is possible to produce only a restricted variety of deformations with the help of the actuators. This is due to the fact that both the number and also the arrangement of the actuators are

fixed. In particular it is usually difficult or even impossible to produce deformations which may be described by higher order Zernike polynomials, such as Z_{10} , Z_{36} , Z_{40} or Z_{64} . The aforementioned US 7,830,611 B2 also proposes to apply transparent actuators directly on the optical surface of an optical element. However, it is difficult to keep scattering losses produced by the transparent actuators low.

US 2010/0201958 A1 discloses a correction device that also comprises two transparent optical elements that are separated from each other by a liquid layer. However, in contrast to the device described in the aforementioned US 7,830,611 B2, a wavefront correction of light propagating through the optical elements is not produced by deforming the optical elements, but by changing their index of refraction locally. To this end one optical element may be provided with heating stripes that extend over the entire surface. The liquid ensures that the average temperatures of the optical elements are kept constant.

WO 2009/152959 A1 discloses an adaptive mirror that is particularly useful for correcting optical wavefronts in EUV projection exposure apparatus. The adaptive mirror comprises a plurality of thermal actuators that are distributed over a back surface of the mirror substrate.

Another approach to deal with heat induced image errors is not to correct errors that have been produced in a plurality of optical elements, but to avoid that such errors occur altogether. This usually involves the locally selective heating or cooling of optical elements so that their temperature distribution becomes at least substantially symmetrical. Any residual heat induced image error of the rotationally symmetric type may then be corrected by more straightforward measures, for example by displacing optical elements along the optical axis.

The additional heating or cooling of optical elements may be accomplished by directing a hot or cool gas towards the element, as it is known from US 6,781,668 B2, for example. However, it is difficult to accurately control the temperature distribution of the optical element with gas flows.

Therefore it has been proposed to direct light beams onto selected portions of optical elements so as to achieve an at least substantially rotationally symmetric temperature distribution on or in the optical element. Usually the light beam is produced by a separate light source which emits radiation having a wavelength that is different from the wavelength of the projection light. The wavelength of this additional light source is determined such that the correction light does not contribute to the exposure of the photoresist, but is still at least partially absorbed by the optical elements or a layer applied thereon.

EP 823 662 A2 describes a correction system of this type in which two additional light sources are provided that illuminate the portions of the mask which surround the (usually slit-formed) field that is illuminated by the projection light. Thus all optical elements in the vicinity of field planes are subjected to three different light beams that heat up the optical element almost in a rotationally symmetrical manner. In other embodiments additional correction light is coupled into the illumination system of the projection exposure apparatus in or in close proximity to a pupil plane. Since, depending on the illumination setting, the center of the pupil plane is often not illuminated during the projection operation, light coupled into this center contributes to a more homogeneous illumination of optical elements that are arranged in or in proximity to a pupil plane in the projection objective.

US 2005/0018269 A1 describes a correction device which makes it possible to heat up certain portions of selected optical elements using a light ray that scans over the portions to be heated. This device can be arranged within the projection ob-
5 jective and makes it possible to increase the temperature very selectively so that an almost perfectly rotationally symmetric temperature distribution can be achieved. If the optical elements are spaced apart from each other by very short distances, as it is often the case, access to the opti-
10 cal elements is restricted, and even if it is possible to reach all points on an optical element, the scanning light ray often impinges on the optical surface at very large angles of incidence. As a result, a substantial fraction of the light energy is reflected at the surface and cannot contrib-
15 ute to the heating of the elements.

Recently the poles in dipole or other multipole illumination settings have become increasingly smaller. The wavefront deformations produced by those optical elements, which are arranged in or in close vicinity to pupil planes in the projec-
20 tion objective, sometimes cannot be sufficiently corrected, or only with very sophisticated and expensive wavefront correction devices.

Unpublished DE 10 2010 029 651 A relates to the control of wavefront correction devices depending on the structures in
25 the mask. In some embodiments also the illumination setting are varied. Variations of the illumination settings, in particular the pole angles, are also described in DE 10 2010 003 167 A.

SUMMARY OF THE INVENTION

30 It is therefore an object of the present invention to provide a method of operating a microlithographic projection exposure apparatus that makes it possible to reduce adverse effects on the imaging quality that are caused by certain illumination

settings, and in particular caused by illumination setting in which only very small off-axis poles are illuminated in an illumination pupil plane.

In accordance with the present invention this object is
5 achieved by a method comprising the following steps:

- a) providing an illumination system having an illumination pupil plane;
- b) providing a projection objective having an objective pupil plane, which is optically conjugate to the illumination pupil plane;
10
- c) providing a mask containing structures;
- d) determining a target spatial irradiance distribution of projection light in the illumination pupil plane, the target spatial irradiance distribution being adapted to the structures contained in the mask;
15
- e) illuminating a portion of the mask with projection light that produces in the illumination pupil plane a modified spatial irradiance distribution, wherein there is an excess area in the illumination pupil plane which is irradiated in the modified spatial irradiance distribution, but is not irradiated in the target spatial irradiance distribution;
20
- f) stopping those light rays, which pass the excess area in the illumination pupil plane, from reaching a light sensitive surface by using a stop that is arranged in the projection pupil plane.
25

The invention is based on the conception that by way of small modifications of an ideal target spatial irradiance distribution in the illumination pupil plane it is often possible to
30 reduce the gradients in the temperature distribution of opti-

cal elements located in or in close vicinity to an objection pupil plane. This, in turn, helps to significantly reduce certain higher order components of the wavefront deformations that are caused by lens heating effects resulting from small off-axis poles, for example. The remaining lower order components of the wavefront deformations can then be easily corrected with conventional means, for example wavefront correction devices comprising deformable plates or adaptive mirrors.

Any deviation from an ideal spatial irradiance distribution in the illumination pupil plane (i.e. an optimum illumination setting) inevitably has an adverse impact on the imaging quality. For that reason the stop arranged in the projection pupil plane ensures that additional projection light, which is used to reduce the gradients in the temperature distribution of optical elements, is absorbed or otherwise stopped from reaching the image plane of the projection objective so that it cannot contribute to the image formation.

Only those lenses and other optical elements, which are arranged between the stop and the light sensitive layer, do not benefit from the modification of the spatial irradiance distribution in the illumination pupil plane. However, modern projection objectives often have one or two intermediate image planes and consequently two or three pupil planes. If the stop is then arranged in the last pupil plane through which projection light propagates on its way towards the light sensitive surface, the number of optical elements that do not benefit from the modification of the spatial irradiance distribution in the illumination pupil plane is small.

Usually the target spatial irradiance distribution will be adapted to the structures contained in the mask such that the structures are imaged with the best imaging quality that is possible in the apparatus. However, there may be also cases

in which the target spatial irradiance distribution is determined not exclusively with a view to the imaging quality, but also with a view to other aspects of the lithography process.

The invention is particularly beneficial if the target spatial irradiance distribution comprises two illuminated poles.
As it has been explained at the outset, in multipole illumination settings the wavefront deformations caused by lens heating effects are much more difficult to correct with conventional wavefront correction devices.

If the target spatial irradiance distribution comprises two illuminated poles, the modified spatial irradiance distribution may differ from the target spatial irradiance distribution only in that the azimuthal widths of the modified poles are increased. Broadening the poles is particularly useful with a view to reducing the contribution of higher order terms of wavefront deformations caused by the poles.

Since the target spatial irradiance distribution is specifically adapted to the mask to be imaged, it will generally be necessary to determine a further target spatial irradiance distribution if a further mask is provided that is different from the mask provided in step c). This further target spatial irradiance distribution will generally be different from the target spatial irradiance distribution that has been determined in step b).

In one embodiment the modified spatial irradiance distribution in the illumination pupil plane is produced in step e) by using an array of reflective or transparent beam deflecting elements. Each beam deflecting element is configured to produce in the illumination pupil plane a light spot at a position that is variable by changing a deflection angle produced by the beam deflecting element. With such a pupil defining unit almost any arbitrary spatial irradiance distribution in the illumination pupil plane can be produced without

using stops that inevitably lead to light losses and thus reduce the throughput of the apparatus.

In some embodiments the modified spatial irradiance distribution has a total irradiated area in the illumination pupil plane that is greater than a total irradiated area of the target spatial irradiance distribution. Since the objective pupil plane is optically conjugated to the illumination pupil plane, the spatial irradiance distribution in the objective pupil plane is, at least if one disregards higher diffraction orders produced by the mask, simply an image of the spatial irradiance distribution in the illumination pupil plane. If the total irradiated area is increased in the modified spatial irradiance distribution, also the total irradiated area of the spatial irradiance distribution in the objective pupil plane will be increased as compared to the target spatial irradiance distribution. This increased area has the effect that the temperature distribution caused by absorption of projection light will be blurred, and consequently higher order contributions to the wavefront deformations are reduced.

However, a similar effect of blurring the temperature distribution in the objective pupil plane can be achieved if in step e) a plurality of different modified spatial irradiance distributions is sequentially produced. For example, the poles of a dipole illumination setting may move over the illumination pupil plane. If the apparatus is of the scanner type in which dies are exposed during scan exposure cycles, and if these modifications are sequentially produced within a single scan exposure cycle, the pupil associated with a particular field point after completion of the scan exposure cycle may nevertheless be completely filled even if the total irradiated area of the modified spatial irradiance distributions is equal to or smaller than the total irradiated area of the target spatial irradiance distribution.

However, it is also possible to produce a first modified spatial irradiance distribution during a scan exposure cycle and a second modified spatial irradiance distribution, which is different from the first modified spatial irradiance distribution, during a subsequent scan exposure cycle.

In some cases the reduction of the wavefront deformations associated with lens heating effects may be reduced with the help of the modified spatial irradiance distribution to such an extent that no further correction of the wavefront deformation is necessary. In most cases, however, it will be expedient to correct residual wavefront deformations caused by rotationally non-symmetrical temperature distributions in optical elements by a wavefront correction device that is arranged in the projection objective. Such a wavefront correction device may comprise an optical element that is deformed to correct the wavefront deformation, and it may be arranged in or in close proximity to a pupil plane of the projection objective.

Usually the stop should be opaque at an area that is an image of the excess area in the illumination pupil plane. Then this opaque area of the stop is able to absorb the projection light that has passed the excess area in the illumination pupil plane and which helps to reduce the temperature gradient on optical elements that are positioned in or in close vicinity to an objective pupil plane. However, it is also possible to use a stop in which this area is not completely opaque so that some light is allowed to pass this area of the stop. This will result in a trade-off between the imaging quality, which is compromised by the light passing through the semi-transparent areas, on the one hand and the positive effect of this portion of the projection light on the temperature distribution of those optical elements that are arranged between the stop and the image plane of the projection objective.

Generally each mask requires a different target irradiance distribution, and each target irradiance distribution requires a stop that is specifically adapted to the target irradiance distribution. For that reason the stop in the objective pupil plane may be received in an exchange holder. A
5 different stop is inserted into the objective pupil plane when a different target angular irradiance distribution is determined.

Instead of exchanging differently configured stops, an adjustable stop may be used. For example, the adjustable stop
10 may comprise displaceable blades or other stop elements. In other embodiments the stop comprises a plurality of pixels each being configured to be individually switched between a transparent state and an opaque state.

Subject of the invention is also a microlithographic projection exposure apparatus that is suitable to carry out the
15 method that has been explained above.

Such a microlithographic projection exposure apparatus comprises an illumination system having an illumination pupil
20 plane, a projection objective having an objective pupil plane, which is optically conjugate to the illumination pupil plane, and a stop that is arranged in the objective pupil plane and that has two apertures.

The two apertures are specifically adapted to a target spatial irradiance distribution that can be produced in the illumination pupil plane and comprises two poles. Such a stop
25 is thus able to efficiently stop light rays which pass an excess area, which is irradiated in the illumination pupil plane in a modified spatial irradiance distribution, but not
30 in the target spatial irradiance distribution, from reaching a light sensitive surface.

If the stop is adjustable and/or is exchangeably received in an exchange holder mounted in the projection objective, the stop can be quickly adapted to different target irradiance distributions.

- 5 An adjustable stop may comprise displaceable stop elements, and the latter may be formed by blades that can be individually displaced, for example pivoted around a common pivot axis that may coincide with the optical axis of the projection objective. In one embodiment the blades extend radially
10 outward from an optical axis of the projection objective, wherein the azimuthal position of the blades is adjustable.

The invention is generally applicable both in apparatus which are designed for projection light having a wavelength in the DUV or VUV wavelength range, for example between 150 nm and
15 300 nm, or in the EUV wavelength range, for example between 2 nm and 30 nm.

BRIEF DESCRIPTION OF THE DRAWINGS

Various features and advantages of the present invention may be more readily understood with reference to the following
20 detailed description taken in conjunction with the accompanying drawings in which:

- FIG. 1 is a meridional section through a projection exposure apparatus in accordance with the present invention;
- 25 FIG. 2 illustrates an exemplary target spatial irradiance distribution in a pupil plane of an illumination system contained in the apparatus shown in FIG. 1;
- FIG. 3 illustrates a spatial irradiance distribution on a lens contained in a projection objective contained
30 in the apparatus shown in FIG. 1;

FIG. 4 illustrates a modified spatial irradiance distribution in the illumination pupil plane;

FIG. 5 illustrates the spatial irradiance distribution on the lens as shown in FIG. 3 if the modified spatial irradiance distribution is produced in the illumination pupil plane;

FIG. 6 is a top view on a stop that is arranged in a pupil plane of the projection objective;

FIG. 7 is a top view on an alternative stop that may be exchanged against the stop shown in FIG. 6;

FIG. 8 is a top view on a still further alternative stop that may be exchanged against the stop shown in FIG. 6;

FIG. 9 is a top view on a stop according to an alternative embodiment in which the stop is formed by an LCD panel;

FIG. 10 is a top view on a stop according to a still further embodiment which comprises adjustable blades;

FIG. 11 illustrates a modified spatial irradiance distribution in the illumination pupil plane at a specific instant during the operation of the apparatus;

FIG. 12 illustrates another modified spatial irradiance distribution in the illumination pupil plane at a specific instant during the operation of the apparatus;

FIG. 13 is a meridional section through an embodiment of the illumination system shown in FIG. 1 in which the pupil defining unit comprises a diffractive op-

tical element, a zoom collimator and a pair of axicon elements;

FIG. 14 is a meridional section through an embodiment of the illumination system shown in FIG. 1 in which the pupil defining unit comprises a mirror array;

FIG. 15 is a flow diagram summarizing important steps of an operating method according to the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

I.

Basic Layout of Projection Exposure Apparatus

FIG. 1 is a meridional section through a projection exposure apparatus in accordance with the present invention. For the sake of clarity, the illustration of FIG. 1 is considerably simplified and not to scale. This particularly implies that different optical units are represented by one or very few optical elements only. In reality, these units may comprise significantly more lenses and other optical elements.

The apparatus, which is denoted in its entirety by 10, comprises an illumination system 12 illuminating a mask 14 that contains minute structures 15 and is supported on a mask stage 16. Those structures 15 that are arranged within an illuminated field of the mask 14 are imaged by a projection objective 18 on a light sensitive surface 20 which is applied on a wafer 22 supported on a wafer stage 24.

The illumination system 12 comprises a light source 26 which is configured to produce projection light 28 which may have a wavelength of 248 nm or 193 nm, for example. The projection light 28 enters an adjustable pupil defining unit 30 which is configured to direct the projection light 28 into various directions that can be controlled by the pupil defining unit

28. As it will be explained further below with reference to FIGS. 13 and 14, the pupil defining unit 30 may contain to this end an exchangeable diffractive optical element or an array of tiltable mirrors, for example.

5 The pupil defining unit 30 is arranged in a focal plane of a first condenser 32 so that the projection light 28 impinging on a subsequent optical integrator 34 is substantially collimated. If the distance between the pupil defining unit 30 and the optical integrator 34 is sufficiently large and the an-
10 gles produced by the pupil defining unit 30 are sufficiently small, the first condenser 32 may also be dispensed with.

In the embodiment shown the optical integrator 34 comprises two arrays of optical raster elements. The optical integrator 34 introduces a divergence of the projection light 28, as it
15 is indicated by a light ray 36a. Immediately behind the optical integrator 34 a first illumination pupil plane 38 is arranged. The spatial irradiance distribution in the first illumination pupil plane 38 is mainly determined by the pupil defining unit 30, whereas the angular irradiance distribution
20 in the first illumination pupil plane 38 is mainly determined by the optical integrator 34.

A second condenser 40 establishes a Fourier relationship between the first illumination pupil plane 38 and a field stop plane 42 which is a field plane. The angular irradiance distribution in the first illumination pupil plane 38 is thus
25 transformed into a spatial irradiance distribution in the field stop plane 42. The optical integrator 34 thus determines the geometry of the field which is illuminated in the field stop plane 42. In turn, the spatial irradiance distribution of the projection light 28 in the first illumination
30 pupil plane 38 is transformed by the second condenser 40 into an angular irradiance distribution in the field stop plane 42. The pupil defining unit 30 thus determines the angular

irradiance distribution of the projection light 28 in the field stop plane 42.

In the field stop plane 42 a field stop 44 is arranged that defines the lateral edges of the field that is illuminated by the illumination system 12 on the mask 14. To this end the field stop plane 42 is imaged, together with the field stop 44, by a field stop objective 46 on the mask 14. The field stop objective 46 contains a second illumination pupil plane 48 which is optically conjugate to the first illumination pupil plane 38.

In this simplified embodiment of the apparatus 10 the projection objective 18 comprises five lenses L1, L2, L3, L4 and L5. The projection objective 18 has an object plane 50, in which the mask 14 is arranged, and an image plane 52, in which the light sensitive surface 20 is arranged. The projection objective 18 contains an intermediate image plane 54 in which an intermediate image of the illuminated portion of the mask 14 is formed.

Between the object plane 50 and the intermediate image plane 54 there is a first objective pupil plane 56, and between the intermediate image plane 54 and the image plane 52 there is a second objective pupil plane 58.

The lens L2 is assumed to be arranged in or in immediate vicinity to the first objective pupil plane 56. Also arranged in close vicinity to the first objective pupil plane 56 is a wavefront correction device 60 which is configured to correct wavefront errors in the projection objective 18. To this end the wavefront correction device 60 comprises a plane parallel plate 62 which can be deformed with the help of actuators indicated at 64. One side of the plane parallel plate may be immersed in a liquid, as it is disclosed in US 7,830,611 B2 which has been mentioned further above, but other types of wavefront correction devices 60 are envisaged as well, for

example devices in which not plates but lenses are deformed, as it is disclosed in US 6,338,823 B1. Also correction devices containing Alvarez plates may be used, as it is disclosed in US 2009/0244509 A1, for example. A very good wave-
5 front correction can be achieved with the device disclosed in US 2010/0201958 A1 mentioned at the outset. In this case, however, it will usually suffice to use a simplified and thus less expensive version thereof.

In the second objective pupil plane 58 a stop 66 is exchange-
10 ably received in an exchange holder 68 so that the stop 66 can be removed from the projection objective 18 and replaced by a different stop without a need to disassemble the projection objective 18.

II.

Function

15 The structures 15 contained in the mask 14 can be imaged on the light sensitive surface 20 with an optimum imaging quality only if the angular irradiance distribution of the projection light in the object plane 50 of the projection objective 18 is specifically adapted to the structures 15 of the
20 mask. The optimum angular irradiance distribution depends, among others, on the orientation, the pitch and the dimensions of the structures 15 to be imaged.

In the following it will be assumed that the structures 15
25 contained in the mask 14 will be imaged on the light sensitive surface 20 with an optimum imaging quality if a dipole illumination setting is established. This means that an angular irradiance distribution is produced in the object plane 50, wherein this angular irradiance distribution corresponds
30 to a spatial irradiance distribution in the first illumination pupil plane 38 in which two poles P1, P2 are illuminated, as it is shown in FIG. 2. It is further assumed that each of the poles P1, P2 has the shape of a ring segment,

wherein the ring has an inner radius r_{ti} and an outer radius r_{to} . The angular width of the ring segments, which is referred to in the following as pole width angle, is denoted by α . In the following this specific spatial irradiance distribution will be referred to as target spatial irradiance distribution, because this is the irradiance distribution which ensures an optimum imaging quality for the specific structures 15 of the mask 14. The target spatial irradiance distribution for the specific mask 14 may be found by carrying out simulations or measurements.

As it is indicated in FIG. 1 by the light rays 36a, 36b, all pupil planes 38, 48, 56 and 58 of the apparatus 10 are optically conjugate. This means that an imaging relationship is established between subsequent pupil planes. Therefore the light rays 36a, 36b emerging from a point in the first illumination pupil plane 38 intersect at each subsequent pupil plane 48, 56 and 58. In the field planes, namely the field stop plane 42, the object plane 50, the intermediate image plane 54 and the image plane 52, all light rays emerging from the pupil planes under the same angle intersect, as it is illustrated in FIG. 1 by the light rays 36b and 36c. Also the field planes are optically conjugate so that an imaging relationship is established between pairs of subsequent field planes.

The optical conjugation of the pupil planes 38, 48, 56 and 58 has the result that the spatial irradiance distribution in the first illumination pupil plane 38 is imaged on all subsequent pupil planes 48, 56 and 58. Strictly speaking this is true only if one disregards the higher diffraction orders that are produced by the structures 15 contained in the mask 14. Only the zeroth diffraction order, which contains most of the projection light, is not deviated by the mask 14, whereas the all other diffraction orders are deviated and thus irradiate the first and second objective pupil planes 56, 58 also

at positions that are not images of the spatial irradiance distribution in the first illumination pupil plane 38. Since these higher diffraction orders contain only a small fraction of the projection light, their impact can be disregarded in the present context.

The imaging of the spatial irradiance distribution in the first illumination pupil plane 38 on the objective pupil planes 56, 58 may cause problems if there are lenses or other optical elements which are arranged in or in close proximity to these pupil planes 56, 58:

In the embodiment shown in FIG. 1 it is assumed that the second lens L2 is arranged very closely to the first objective pupil plane 56. FIG. 3 is a top view on the lens L2 illustrating the spatial irradiance distribution obtained on the lens L2 if the spatial irradiance distribution shown in FIG. 2 is produced in the first illumination pupil plane 38 of the illumination system 12. As mentioned above, the contributions of the higher diffraction orders are disregarded. It can be seen that the spatial irradiance distribution on the second lens L2 is basically an image of the spatial irradiance distribution in the first illumination pupil plane 38. Therefore the spatial irradiance distribution on the second lens L2 also comprises two poles P1', P2' whose size in absolute terms depends on the magnification which is produced by the optical elements that are arranged between the first illumination pupil plane 38 and the first projection pupil plane 56.

Compared to the overall surface of the second lens L2 the poles P1', P2' are quite small. Since the lens L2 absorbs a certain - although small - portion of the projection light, the second lens L2 will gradually heat up. However, since the heat is only produced at the surface areas and the volume through which the projection light 28 passes, steep tempera-

ture gradients occur in the second lens L2. The temperature profile of the second lens L2 also changes its optical properties, mainly because the heated portions of the lens L2 change their index of refraction and/or their volume so that
5 the lens L2 undergoes deformations.

The wavefront correction device 60 may be capable of correcting a part of the wavefront deformations that are caused by the local heating of the second lens L2. However, the smaller the poles P1, P2 are in the first illumination pupil plane
10 38, the greater will be the temperature gradient in the second lens L2, and consequently the wavefront deformations produced by the second lens L2 will contain steep waves. If the wavefront deformation is expanded into a set of Zernike polynomials, the steepness of these waves manifests itself in
15 that the contributions from Zernike polynomials of a higher order are very significant.

Wavefront deformations containing significant contributions associated with higher order Zernike polynomials, however, are difficult to correct with the help of the wavefront correction device 60. The main reason for this is that the plate
20 62 cannot be deformed such that it has similar steep deformations at a short distance. Although there are some wavefront correction devices available that are capable of correcting almost any arbitrary wavefront deformation (see, for example,
25 US 2010/0201958 mentioned further above), these devices are either very expensive, produce a considerable amount of scattering light or are specifically adapted to correct a specific type of wavefront deformations.

In order to avoid adverse lens heating effects that are produced by irradiating very small poles P1', P2' on the second
30 lens L2, the pupil defining unit 30 does not produce the target spatial irradiance distribution in the first illumination pupil plane 38 that is shown in FIG. 2, but a modified spa-

tial irradiance distribution that is shown in FIG. 4. This modified spatial irradiance distribution comprises two modified poles MP1, MP2 each having a greater total irradiated area as compared to the poles P1, P2 of the target spatial irradiance distribution shown in FIG. 2. More specifically, the modified poles MP1, MP2 have a smaller inner diameter r_{mi} , a greater outer diameter r_{mo} and a greater pole width angle α . Thus there is an excess area 70 in each modified pole MP1, MP2 that is only irradiated in the modified spatial irradiance distribution, but not in the target spatial irradiance distribution. The excess area 70 is formed in FIG. 4 by the hatched area outside the dashed lines that indicate the poles P1, P2 of the target irradiance distribution.

FIG. 5 shows the irradiance distribution that is observed on the second lens L2 if the modified spatial irradiance distribution shown in FIG. 4 is produced in the first illumination pupil plane 38. Due to the imaging relationship with respect to the first illumination pupil plane 38, also the modified poles MP1', MP2' of the spatial irradiance distribution on the second lens L2 have a greater irradiated area than the poles P1', P2' that would be obtained with the target spatial irradiance distribution.

Thus the projection light is distributed over a greater area on the surface on the second lens L2. This has a positive effect on the steepness of the wavefront deformations that are produced by the heating effects occurring in the second lens L2. More specifically, the wavefront deformations now contain smaller contributions from higher order Zernike polynomials, and due to this reduced "waviness" the wavefront correction device 60 is now capable to reduce the wavefront deformations to tolerable values.

However, if the light, which passes through the excess area 70 of the modified spatial irradiance distribution, would be

allowed to impinge also on the light sensitive surface 20, the imaging quality would deteriorate. This is because it has been assumed that the best imaging quality is obtained not with the modified spatial irradiance distribution shown in FIG. 4, but with the target spatial irradiance distribution shown in FIG. 2.

In order to stop the light, which passes through the excess area 70 in the first illumination pupil plane 38, from reaching the light sensitive layer 20, the stop 66 is arranged in the second objective pupil plane 58.

In FIG. 6, which is a top view on the stop 66, it can be seen that the stop 66 has two apertures A1, A2 which have exactly the size and position of the images of the poles P1, P2 that could be observed in the first illumination pupil plane 38 if the target spatial irradiance distribution was produced. As a result of this configuration of the stop 66, the light rays which pass the excess area 70 impinge on the opaque areas 72 that are indicated in FIG. 6 by broken lines. The opaque areas 72 are thus images of the excess areas 70 of the modified spatial irradiance distribution in the first illumination pupil plane 38.

Referring again to FIG. 1, a light ray 74 shown as broken line is assumed to pass through the excess area 70 in the illumination pupil plane 38. This light ray propagates through all subsequent lenses of the illumination system 12 and of the projection objective 18, and in particular through the second lens L2 of the projection objective 18 which is arranged in close vicinity to the first objective pupil plane 56. This light ray 74 thus contributes to the heating of the second lens L2 with the effect that the temperature distribution is spatially blurred.

However, this particular light ray 64 is not allowed to pass through the stop 66 and thus does not contribute to the image

formation on the light sensitive surface 20. In other words, only those portions of the projection light 28 contribute to the image formation on the light sensitive surface 20 which originated from the smaller poles P1, P2 of the target spatial irradiance distribution in the first illumination pupil plane 38.

Usually the zeroth and one or more of the higher diffraction orders are used to form the image on the light sensitive layer 20, and from these higher diffraction orders only light that passes through pupil planes at the same positions contributes to the formation of an image. Thus the stop 66 may absorb also higher diffractions orders, but not those portions of these orders that contribute to the image formation.

The stop 66 thus ensures that the imaging quality is not compromised by increasing the size of the poles P1, P2. On the other hand, this increase (in particular of the pole width angle α) helps to reduce adverse lens heating effects to such an extent that the remaining wavefront deformations can be easily corrected with the help of a comparatively straightforward wavefront correction device 60.

The increased size of the modified poles MP1, MP2 of the modified spatial irradiance distribution, which is produced in the first illumination pupil plane 38, is "felt" only by those optical elements that are arranged between the pupil defining unit 30 and the stop 66. Here the larger modified poles MP1, MP2 help to reduce undesired effects produced by local heating of optical elements.

All optical elements following the stop 66, here the lens L5, are only subjected to the portions of the projection light 28 that do not pass the excess area 70 in the first illumination pupil plane 38 and may thus be associated with the target spatial irradiance distribution. These optical elements do not benefit from the additional light that passes through the

excess area 70 in the first illumination pupil plane 38. However, the number of lenses arranged between the last objective pupil plane and the image plane 52 is usually small, and consequently only a few optical elements are able to contribute to higher order wavefront deformations as a result of lens heating effects. Furthermore, it should also be considered that the projection light has already been attenuated when passing through the preceding lenses L1, L2, L3 and L4. Therefore the adverse lens heating effects produced by the last lens L5 will generally be less significant than the effects produced by the second lens L2 that is arranged in close vicinity to the first objective pupil plane 56.

As a matter of course, a certain portion of projection light 28 is lost by absorption on the stop 66. However, this portion is much smaller than the opaque area 72 shown in FIG. 6, on which the projection light having passed the excess area 70 impinges, might suggest. This is because in a real apparatus 10 the excess area 70 is much smaller than it is shown for the sake of illustration in FIG. 4. It has turned out that it often suffices to increase the size of the poles only by a very small amount. For example, increasing the pole width angle α by only 2% significantly reduces the contribution of higher Zernike polynomials to the overall wavefront deformation. The light loss of 2%, which corresponds to a reduction of the throughput by a similar magnitude, is by far outweighed by the substantial gain in imaging quality.

From the foregoing it should have become clear that the configuration of the stop 66 has to be specifically adapted to the target spatial irradiance distribution which has been determined for a particular mask 14. This implies that if another mask 14 containing different structures 15 shall be imaged, it will generally be necessary to determine a different target spatial irradiance distribution. This, in turn, requires that another stop 66 is inserted into the projection

objective 18. The apertures of the new stop may be images of the new target spatial irradiance distribution.

FIGS. 7 and 8 are top views on exemplary stops 66', 66" that may be alternatively inserted into the projection objective 18 using the exchange holder 68. The stop 66' shown in FIG. 7 is provided with four apertures A1, A2, A3, A4 each having a shape of a trapezoid and being arranged along a circumference of the stop 66' with a fourfold rotational symmetry. The stop 66" shown in FIG. 8 has two trapezoidal apertures A1, A2, a small central aperture A3 and an annular aperture A4 that verges into the trapezoidal apertures A1 and A2.

III.

Alternative Embodiments

a) Adjustable stops

Often the optimum target irradiance distribution in the first illumination pupil plane 38 is determined on the basis of measurements during an optimization process. In such a process it is necessary to finely adjust the target spatial irradiance distribution in the first illumination pupil plane 38. A pupil defining unit 30 which is capable to finely adjust the spatial irradiance distribution in the first illumination pupil plane 38 will be explained further below with reference to FIG. 14. However, it will then also be necessary to finely adjust the apertures of the stop 66. Although the production of a suitable stop 66 is not difficult, it may be a time consuming process to produce a new stop 66, to remove the former stop 66 from the exchange holder 68 and to insert the new stop into the projection objective 18.

Also if the optimum target spatial irradiance distribution is determined by simulation, it is sometimes necessary to make fine adjustments of the target spatial irradiance distribu-

tion if measurements confirm that the simulation does not fully reflect the physical properties of the apparatus 10.

In order to be able to perform fine adjustments of the apertures in the stop 66, a stop 166 as shown in the top view of FIG. 9 may be used. The stop 166 is substantially formed by an LCD panel comprising a plurality of pixels 80 that are arranged in a two dimensional array. Each pixel 80 is configured such that it can be individually switched, for example by applying a voltage, between a transparent and an opaque state. To this end the pixels 80 may contain liquid crystals and polarizers, as it is known in the art as such. By individually switching the pixels 80 between the transparent and the opaque state, it is possible to define, within the limits of the resolution provided by the pixel array, almost any arbitrary shape of one or more "apertures" (in the sense of transparent areas), as it is shown in FIG. 9 for two apertures A1, A2.

FIG. 10 is a top view on another adjustable stop which is denoted in its entirety by 266. This stop is particularly suited to adjust the pole width angle α of poles in dipole illumination settings. To this end the stop 266 comprises an opaque ring 82 and a central opaque disc 84 which is coaxially arranged with respect to the ring 82. Four blades 86 are pivotably connected to the disc 84 such that they are allowed to pivot around a pivotal axis which coincides with the optical axis of the projection objective 18. The inner and outer radius of the apertures A1, A2 are fixedly determined by the disc 84 and the ring 82, but the angular width of the apertures A1, A2 can be freely adjusted by moving the blades 86, as it is indicated by double arrows 88. A broken line 90 indicates the irradiance distribution that is obtained on the stop 266 if a modified spatial irradiance distribution is produced in the first illumination pupil plane 38.

In other embodiments also the inner and outer radius of the apertures A1, A2 can be adjusted, too. In that case the opaque ring 82 may be formed by an iris diaphragm, and the central disk 84 may comprise a similar mechanism that enables
5 the realization of different diameters of the disk 84.

b) Pole movement

Instead of producing modified poles MP1, MP2 having a total irradiated area that is greater than the irradiated area of the poles P1, P2 of the target spatial irradiance distribution (see FIG. 4), it is also possible to produce sequentially at varying positions different modified poles MP1', MP2' having the same size as (or being even smaller than) the poles P1, P2 of the target spatial irradiance distribution. This approach is illustrated in FIG. 11 in which the modified
10 poles MP1', MP2' in the first illumination pupil plane 38 are shown at a certain instant. The poles MP1', MP2' have the same shape and size as the poles P1, P2 of the target spatial irradiance distribution (shown in broken lines), but are rotated around the optical axis by a certain rotational angle. During operation of the apparatus 10 this rotational angle is
15 varied between subsequent scan exposure cycles or even within a single scan exposure cycle. As a result, the irradiance distribution produced on the second lens L2 is - in the time average - blurred. Thus a similar effect is achieved as with
20 the larger poles MP1, MP2 shown in FIG. 4.

FIG. 12 illustrates another scheme to move modified poles MP1", MP2" sequentially within a single scan exposure cycle or between subsequent scan exposure cycles to achieve the effect of blurring the irradiance distribution on the second
30 lens L2 in the time average. According to this scheme the modified poles MP1", MP2" also have the same shape and size as the poles P1, P2 of the target spatial irradiance distribution, but here the modified poles MP1", MP2" are not ro-

tated around the optical axis, but are moved radially along a diameter of the first illumination pupil plane 38.

c) Pupil defining unit - diffractive optical element

FIG. 13 is a meridional section through an illumination system 12 according to an embodiment in which the pupil defining unit 30 comprises a diffractive optical element 92, a zoom collimator lens 94 and a pair of axicon elements 96, 98.

The projection light 28 emitted by the light source 26 is first expanded in a beam expansion unit 100 and then impinges, after reflection from two planar beam folding mirrors 102, 104, on the diffractive optical element 92. As can be seen in the enlarged cut-out 106, the diffractive optical element 92 comprises a substrate 108 on which minute diffractive structures 110 are formed. The diffractive optical element 92, which may be realized as a computer generated hologram (CGH), directs the impinging projection light 28 into various directions that are determined by the structures 110. The divergent projection light is then collimated by the zoom collimator lens 94. The latter can be displaced (see double arrow 112) along an optical axis OA of the illumination system 12 with the help of a first actuator 110 that is connected to an overall system control 116. By displacing the zoom collimator lens 94 along the optical axis OA the diameter of the collimated projection light beam can be varied.

The collimated light beam then impinges on the axicon elements 96, 98 which each have a planar surface on one side and a conical surface on the opposite side. If the axicon element 96, 98 are spaced apart along the optical axis, as it is shown in FIG. 13, the irradiance distribution at the planar entrance surface of the first optical element 96 is radially shifted outward. The amount of this shift can be varied by displacing one of the axicon elements, here the second axicon element 98, along the optical axis OA with the help of a sec-

ond actuator 114 that is also connected to the overall system control 116 (see double arrow 115).

Thus there are two degrees of freedom available to vary the irradiance distribution on the optical integrator 34 and the subsequent first illumination pupil plane 38. The diffractive optical element 92 may be configured such that it produces the target spatial irradiance distribution in the far field. The available two degrees of freedom may then be used to produce different modified spatial irradiance distributions. For example, if the diffractive optical element 92 produces two poles in the far field, the size of the poles can be varied with the help of the zoom collimator lens 94. The radial position of the poles can be varied by displacing the second axicon element 98 along the optical axis OA with the help of the second actuator 114.

d) Pupil defining unit - mirror array

FIG. 14 is a meridional section through an illumination system 12 according to another embodiment in which the pupil defining unit 30 comprises an array 118 of small mirrors 120 that can be individually tilted about two orthogonal tilt axes. To this end the mirror array 118 is connected to a mirror control unit 122 which is, in turn, connected to the overall system control 116.

The pupil defining unit 30 further comprises a prism 124 which is used to direct impinging light towards the mirrors 120 and to direct the projection light reflected from the mirrors 120 towards the first condenser 32. More details with regard to the spatial light modulator 30 and the mirror array 118 contained therein can be gleaned from US 2009/0115990 A1, for example.

Each mirror 120 produces a small spot on the optical integrator 34 whose position can be freely varied by appropriately

tilting the respective mirror 120. This makes it possible to achieve a unique flexibility in producing almost any arbitrary spatial irradiance distribution in the first illumination pupil plane 38.

5 e) EUV

In the aforementioned embodiments it has been assumed that the apparatus 10 uses projection light having a wavelength in the DUV wavelength range, for example 193 nm. However, the invention is equally applicable in apparatus that are designed for EUV projection light, for example light having a wavelength of about 13.5 nm. In that case the irradiance distribution in an illumination pupil plane may also be produced, similar to the embodiment shown in FIG. 14, with the help of an array of adjustable mirrors, for example using
10 tilttable mirrors facets of a field facet mirror contained in
15 the EUV illumination system.

As wavefront correction device 60 an adaptive mirror may be used, for example the mirror that is disclosed in the aforementioned WO 2009/152959 A1. The stop in the projection objective may have a similar design as the stop 66 used in the
20 embodiments described above.

IV.

Important Method Steps

FIG. 15 is a flow diagram that illustrates important method steps of the above described method of operating a projection exposure apparatus.
25

In a first step S1 an illumination system having an illumination pupil plane is provided.

In a second step S2 a projection objective having an objective pupil plane, which is optically conjugate to the illumination pupil plane, is provided.
30

In a third step S3 a mask containing structure is provided.

In a fourth step S4 a target spatial irradiance distribution of projection light in the illumination pupil plane is determined. The target spatial irradiance distribution is adapted
5 to the structures contained in the mask.

In a fifth step S5 a portion of the mask is illuminated with projection light that produces in the illumination pupil plane a modified spatial irradiance distribution. There is an excess area in the illumination pupil plane which is irradiated in the modified spatial irradiance distribution, but is
10 not irradiated in the target spatial irradiance distribution.

In a sixth step S6 those light rays are stopped, which pass the excess area in the illumination pupil plane, from reaching a light sensitive surface by using stop that is arranged
15 in the projection pupil plane.

The above description of the preferred embodiments has been given by way of example. From the disclosure given, those skilled in the art will not only understand the present invention and its attendant advantages, but will also find apparent various changes and modifications to the structures and methods disclosed. The applicant seeks, therefore, to cover all such changes and modifications as fall within the spirit and scope of the invention, as defined by the appended
20 claims, and equivalents thereof.
25

CLAIMS

=====

1. A method of operating a microlithographic projection exposure apparatus, comprising the following steps:
 - a) providing an illumination system (12) having an illumination pupil plane (38);
 - 5 b) providing a projection objective (18) having an objective pupil plane (58), which is optically conjugate to the illumination pupil plane (38);
 - c) providing a mask (14) containing structures (15);
 - 10 d) determining a target spatial irradiance distribution of projection light (28) in the illumination pupil plane (38), the target spatial irradiance distribution being adapted to the structures (15) contained in the mask (14);
 - 15 e) illuminating a portion of the mask (14) with projection light that produces in the illumination pupil plane (38) a modified spatial irradiance distribution, wherein there is an excess area (70) in the illumination pupil plane which is irradiated in the modified spatial irradiance distribution, but is not irradiated in the target spatial irradiance distribution;
 - 20 f) stopping those light rays (36c), which pass the excess area (70) in the illumination pupil plane (38), from reaching a light sensitive surface (20) by using a stop (66; 166; 266) that is arranged in the projection pupil plane (58).
 - 25

2. The method claim 1, wherein the projection objective (18) has a plurality of objective pupil planes (56, 58), and wherein the stop (66; 166; 266) is arranged in the last pupil plane (58) through which projection light (26) propagates on its way towards the light sensitive surface (20).
5
3. The method of claim 1 or 2, wherein the target spatial irradiance distribution is adapted to the structures (15) contained in the mask (14) such that the structures (15) are imaged with the best imaging quality that is possible in the apparatus (10).
10
4. The method of any of the preceding claims, wherein the target spatial irradiance distribution comprises two illuminated poles (P1, P2).
- 15 5. The method of any of the preceding claims, wherein the modified spatial irradiance distribution has a total irradiated area that is greater than a total irradiated area of the target spatial irradiance distribution.
6. The method of any of the preceding claims, wherein in step e) a plurality of different modified spatial irradiance distributions are sequentially produced.
20
7. The method of any of the preceding claims, wherein wavefront deformations caused by rotationally non-symmetrical temperature distributions in optical elements are corrected by a wavefront correction device (60) that is arranged in the projection objective (18).
25
8. The method of any of the preceding claims, wherein the stop (66; 166; 266) is opaque at an area that is an image of the excess area (70) in the illumination pupil plane (38).
30

9. The method of any of the preceding claims, wherein the stop (66; 166; 266) is received in an exchange holder (68), and wherein a different stop is inserted into the objective pupil plane (58) when a different target angular irradiance distribution is determined.
10. The method of any of the preceding claims, wherein the stop is an adjustable stop (166; 266).
11. A microlithographic projection exposure apparatus, comprising
- an illumination system (12) having an illumination pupil plane (38),
 - a projection objective (18) having an objective pupil plane (58), which is optically conjugate to the illumination pupil plane (38), and
 - a stop (66; 166; 266) that is arranged in the objective pupil plane (58),
- wherein the stop (66; 166; 266) has two apertures (A1, 2; A1 to A4).
12. The apparatus of claim 11, wherein the stop (66; 166; 266) is adjustable and/or is exchangeably received in an exchange holder (68) mounted in the projection objective (18).
13. The apparatus of any of claims 11 or 12, wherein the stop (266) is adjustable and comprises displaceable stop elements (86).
14. The apparatus of claim 13, wherein the stop elements are formed by blades (86) that can be individually displaced.

15. The apparatus of claim 14, wherein the blades (86) extend radially outward from an optical axis of the projection objective (18), and wherein an azimuthal position of the blades (86) is adjustable.

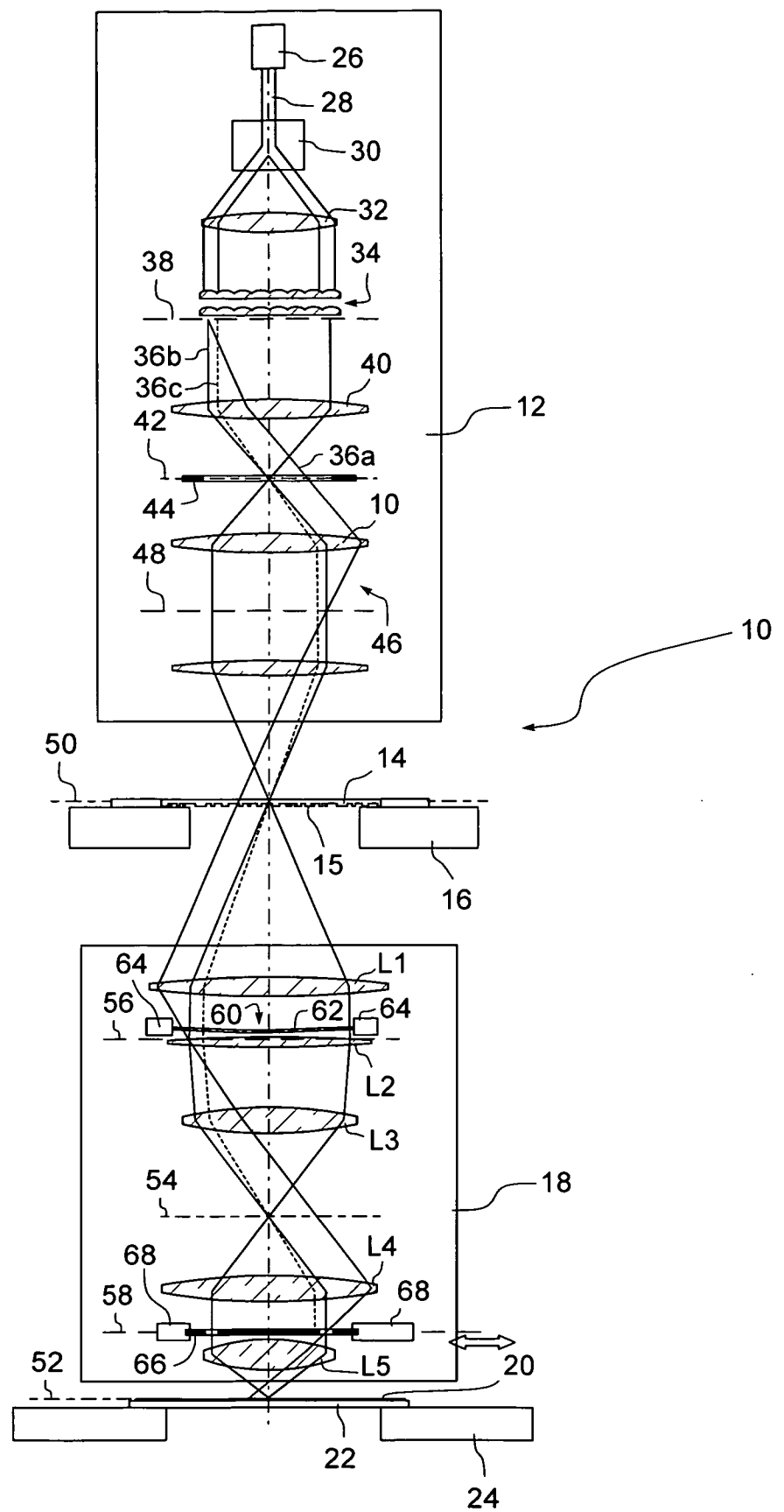


Fig.1

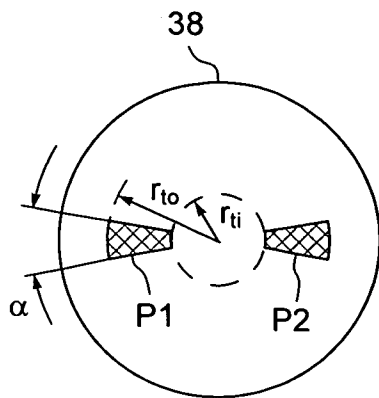


Fig. 2

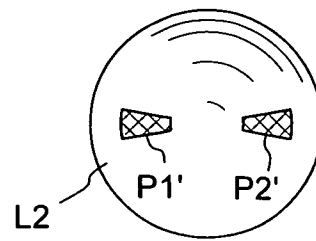


Fig. 3

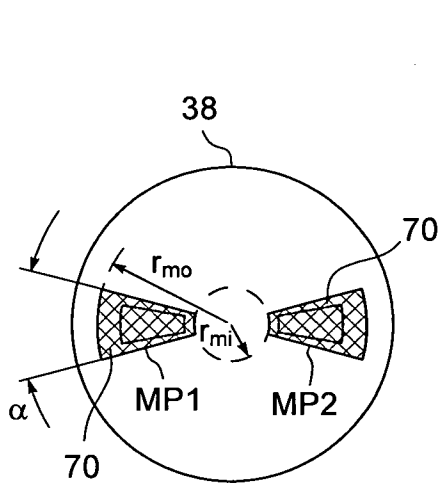


Fig. 4

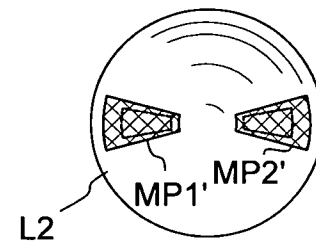
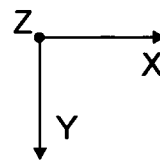


Fig. 5

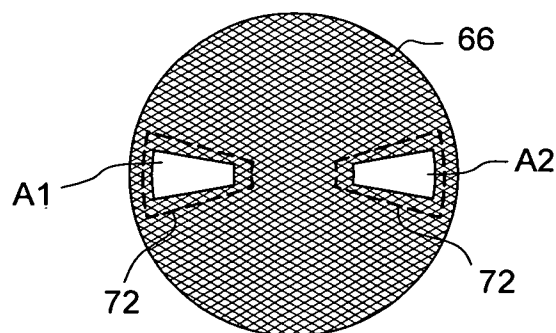


Fig. 6

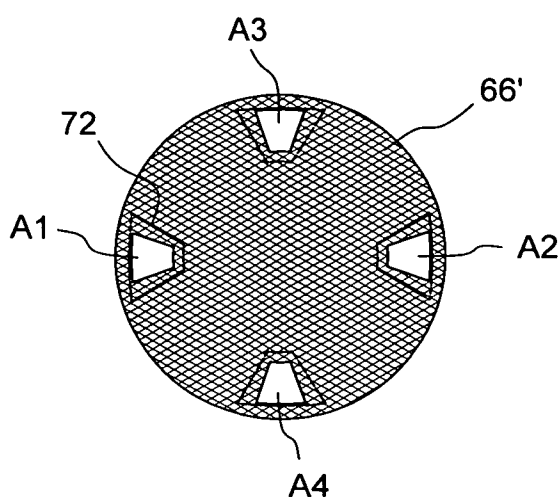


Fig. 7

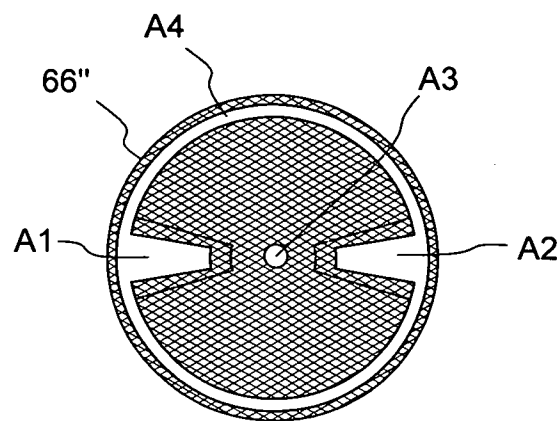


Fig. 8

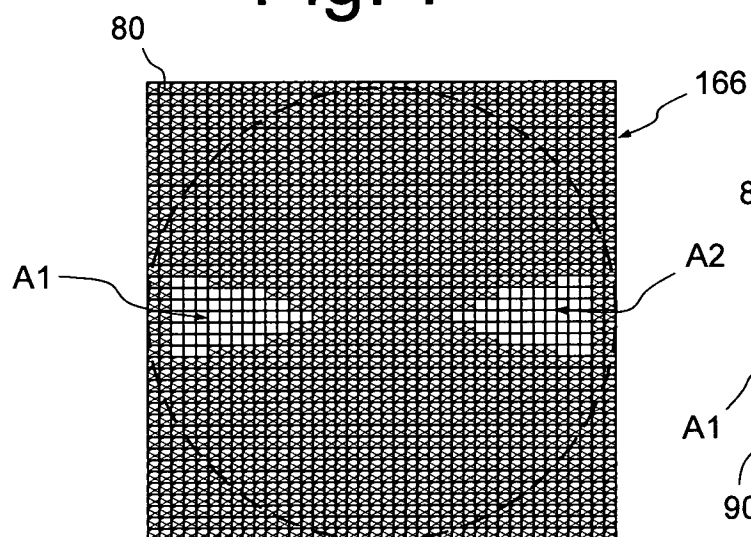


Fig. 9

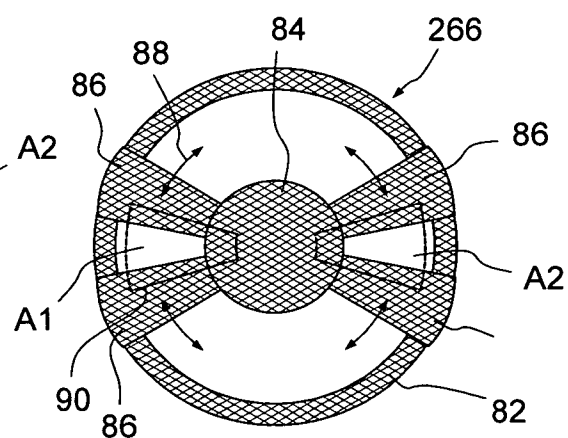


Fig. 10

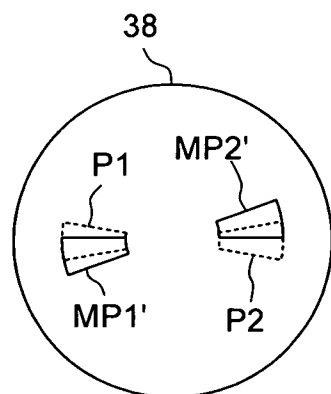


Fig. 11

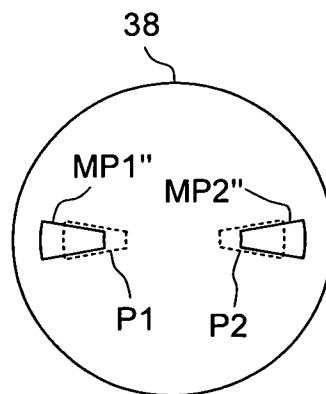
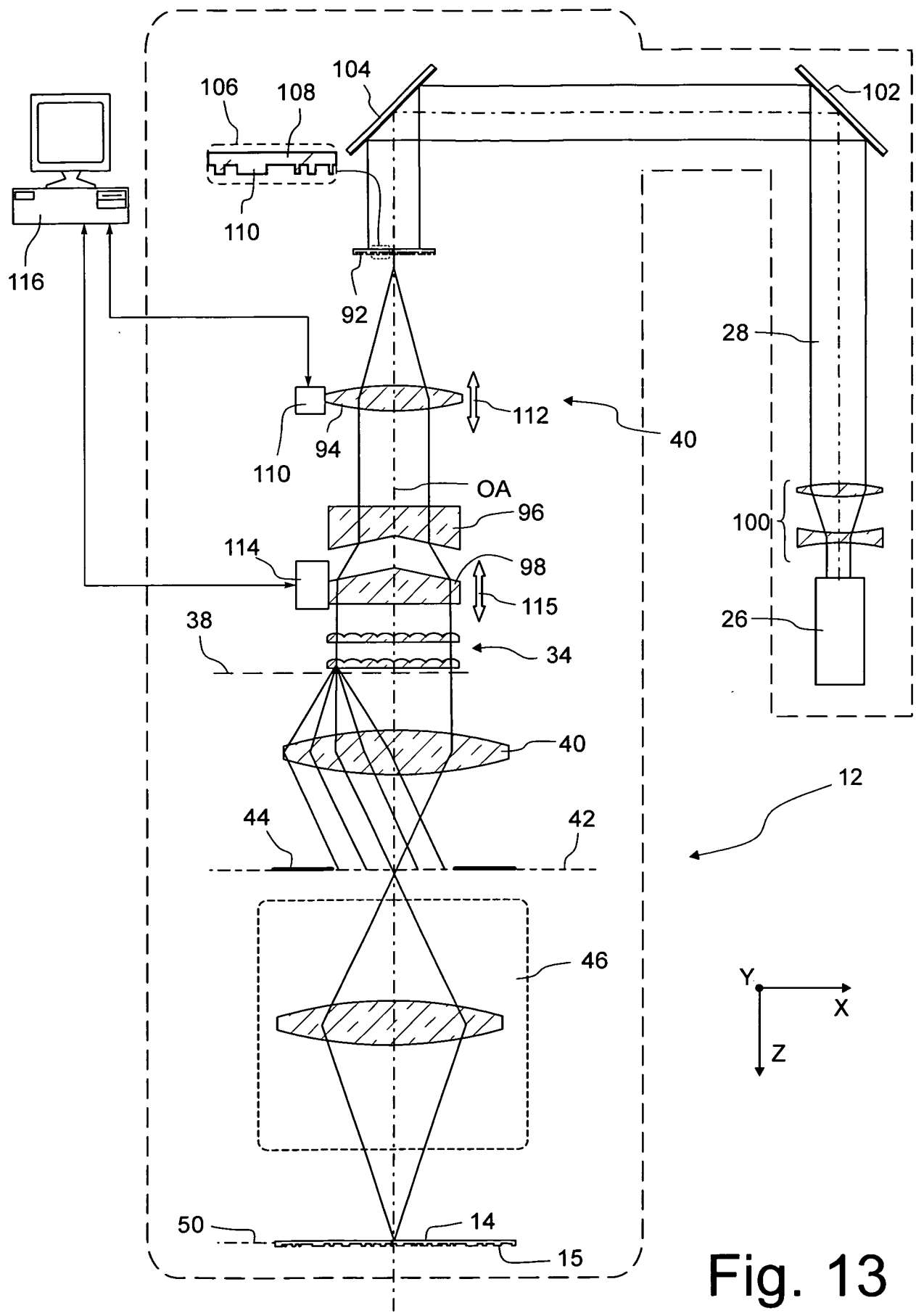
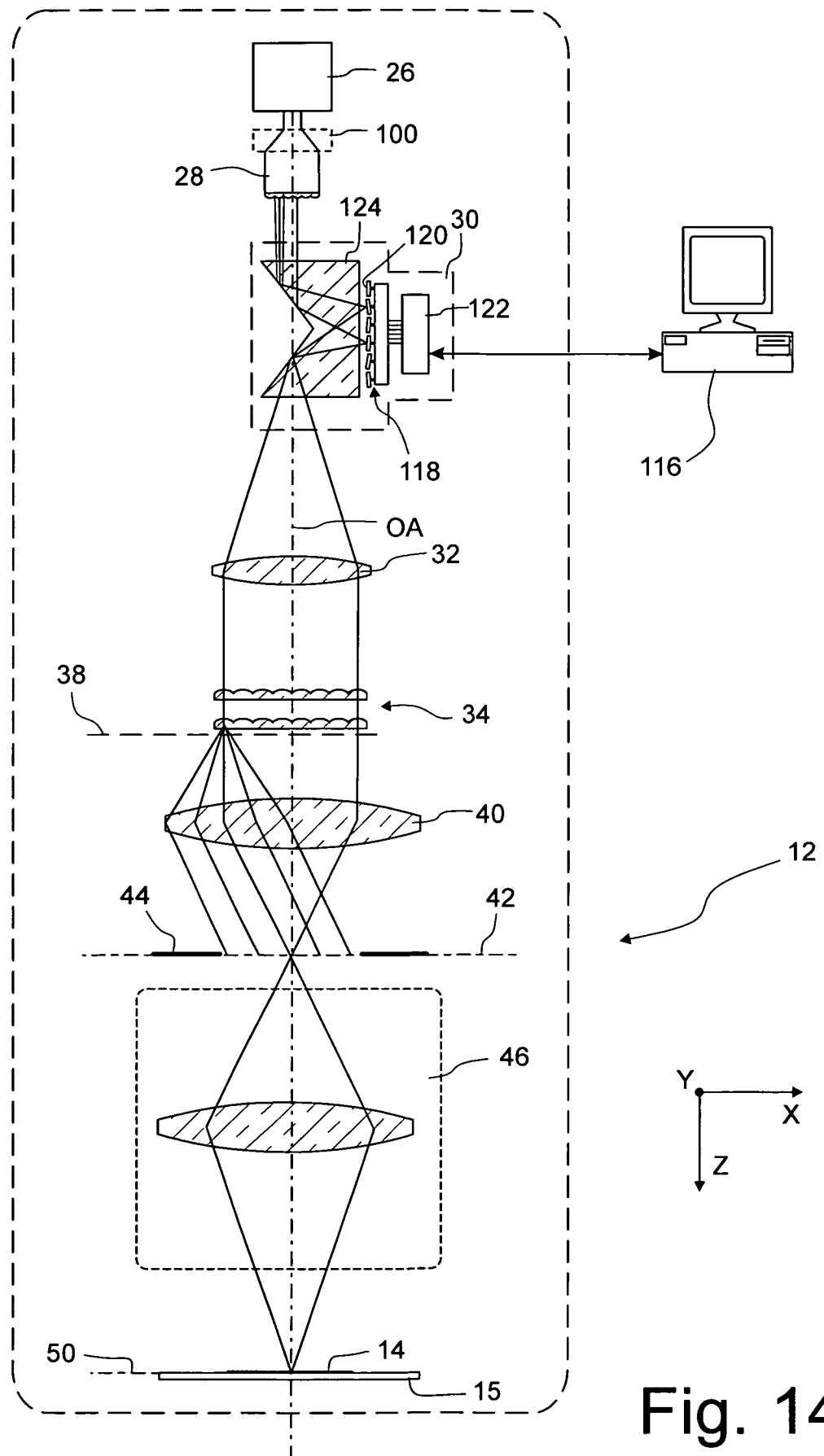


Fig. 12





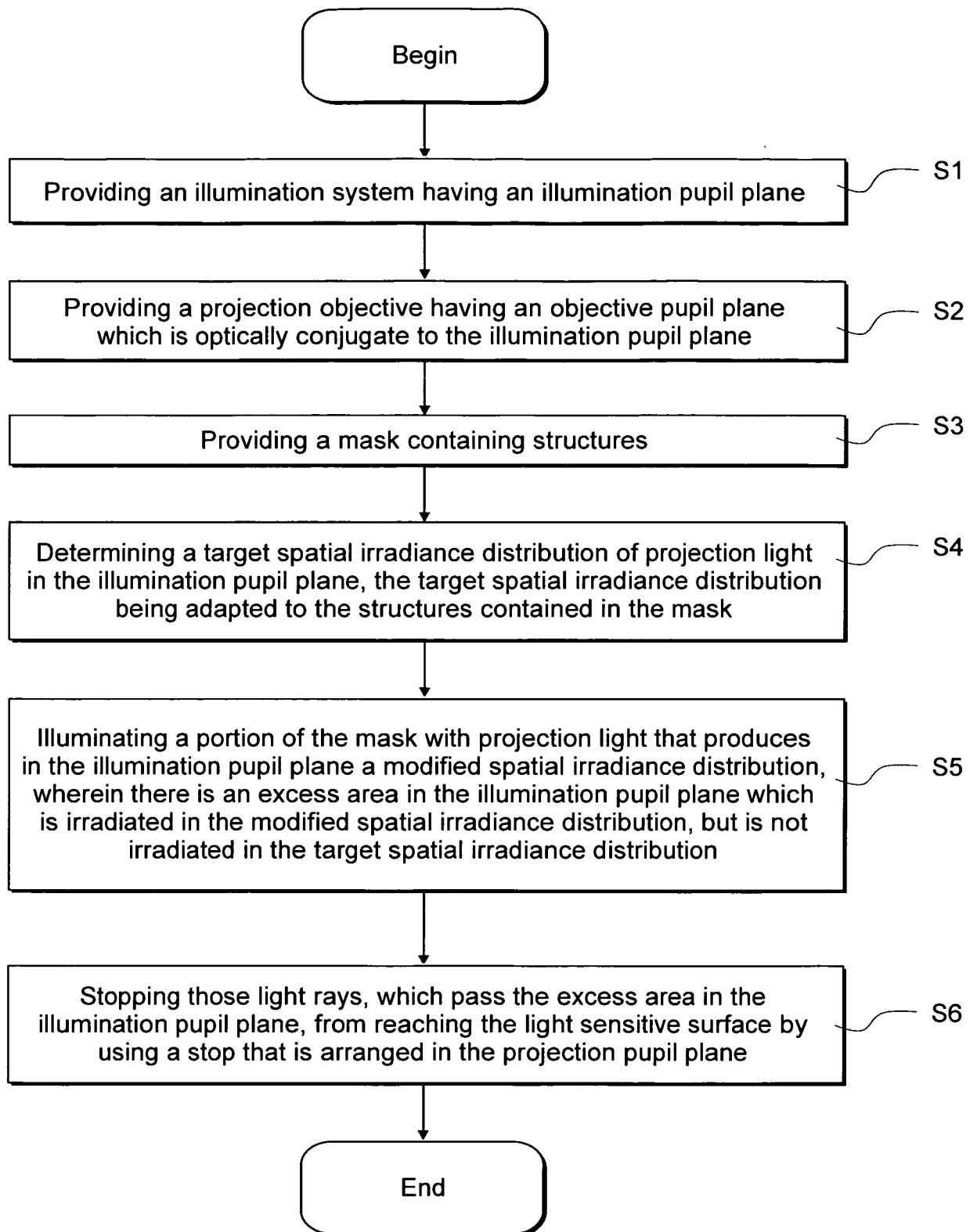


Fig. 15

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/001264

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G03F7/20 H01L21/00
 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)
 G03F 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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/177123 A1 (TEL WIM T [NL] ET AL TEL WIM TJIBBO [NL] ET AL) 2 August 2007 (2007-08-02)	1-5,8-11
Y	paragraphs [0006], [0007], [0009], [0010], [0047] - [0067]; figures 1a, 3, 6	7,12-15
X	US 6 233 041 B1 (SHIRAISHI NAOMASA [JP]) 15 May 2001 (2001-05-15)	11
Y	figure 1	12-15
Y	US 2010/201958 A1 (HAUF MARKUS [DE] ET AL) 12 August 2010 (2010-08-12) cited in the application abstract	7
Y	EP 0 794 462 A2 (SIEMENS AG [DE]; TOSHIBA KK [JP] INFINEON TECHNOLOGIES AG [DE]; TOSHIBA) 10 September 1997 (1997-09-10) figures 3-6	12-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Information on patent family members

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