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

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **FIOLKA, Damian** [DE/DE]; Heckenrosenweg 36, 73447 Oberkochen (DE). **HEIL, Tilmann** [DE/DE]; Schlesische Str. 39, 73431 Aalen (DE). **GOEHNERMEIER, Aksel** [DE/DE]; Hannah-Arendt-Strasse 6, 73431 Aalen (DE). **GRAEUPNER, Paul** [DE/DE]; Kälblesrainweg 21, 73430 Aalen (DE).

(74) Agents: **SCHWANHÄUSSER, Gernot** et al.; Ostertag & Partner, Epplestr. 14, 70597 Stuttgart (DE).

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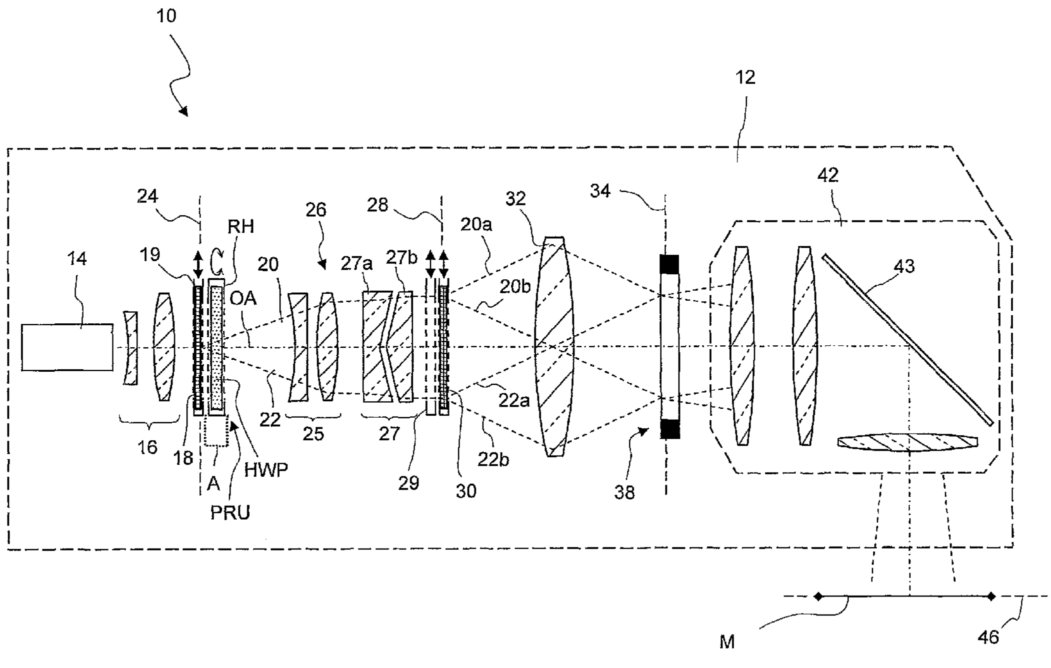
(54) **Title:** ILLUMINATION SYSTEM FOR A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS



(57) **Abstract:** An illumination system for a microlithographic projection exposure apparatus has a light source (14) emitting linearly polarized light that has a fixed polarization direction (PDi). A polarization rotation unit (PRU, PRU', PRU '') is provided that is configured to rotate the polarization direction on demand by a rotational angle $\alpha \neq 0^0$. This makes it possible to adapt the polarization direction to different masks (M) with minimal losses of the light intensity.

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ILLUMINATION SYSTEM FOR A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of US provisional patent application 60/619,927 filed October 15, 2004.

BACKGROUND OF THE INVENTION

1. Field of the invention

The invention relates generally to illumination systems for microlithographic projection exposure apparatus. More particularly, the invention relates to illumination systems that make it possible to illuminate a mask with projection light having a linear polarization state.

2. Description of Related Art

Microlithography (also called photolithography) is a technology for the fabrication of integrated circuits, liquid crystal displays and other microstructured devices. More particularly, 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) light. Next, the wafer with the photoresist on top is exposed to projection light through a mask in a projection exposure apparatus, such as a step-and-scan tool. 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.

A projection exposure apparatus typically includes an illumination system, a projection lens and a wafer alignment stage for aligning the wafer coated with the photoresist. The illumination system illuminates a region of the mask with an illumination field that may have the shape of an elongated rectangular slit. As the technology for manufacturing microstructured devices advances, there are ever increasing demands also on the illumination system. For example, it has been found out that illuminating the mask with linearly polarized projection light may considerably improve the imaging of the mask onto the photoresist.

From US 5 442 184 A it is known to use a rotatable polarization filter for changing the polarization direction during an exposure. However, this results in different light intensities on the mask depending on the position of the polarization filter.

WO 2004/010963 A1 discloses an illumination system comprising polarization status switching means for changing a linear polarization state to a non-linear polarization state.

WO 2004/051717 A1 discloses an illumination system comprising polarization status switching means for changing a specific linear polarization state to a non-polarized state and vice versa.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an illumination system that makes it possible to flexibly adjust the polarization direction to different masks.

This object is, according to the invention, achieved by an illumination system that has a light source emitting linearly polarized light that has a fixed polarization direction. A polarization rotation unit is provided that is configured to rotate the polarization direction on demand by a rotational angle $\alpha \neq 0°$.

This makes it possible to adapt the polarization direction to different masks without incurring substantial optical losses as is the case with polarization filters that pass only one single polarization component.

The polarization rotation unit may be configured to rotate the polarization direction by at least two different rotational angles or even by arbitrary rotational angles. A rotation by arbitrary angles may be achieved, for example, if the polarization rotation unit comprises a half-wave plate that may be (detachably) received in an exchange holder. The exchange holder, which is located in the path of light, is configured to rotate the half-wave plate around an axis that coincides with an optical axis of the illumination system or is aligned parallel thereto. An actuator may be provided for rotating the half-wave plate in the exchange holder upon an appropriate command signal from a control unit.

If the half-wave plate can be received in various different angular positions within the exchange holder without the possibility to rotate the half-wave plate, only a restricted number of rotational angles may be achieved. In many cases, however, this will be sufficient.

The half-wave plate may be made of an intrinsically birefringent material or a material in which birefringence is induced by mechanical stress.

Instead of a half-wave plate a combination of a first half-wave plate and a second half-wave plate may be used.

These plates are arranged such that a principal axis of the first half-wave plate forms an angle of 45° with a principal axis of the second half-wave plate. This combination ensures that the polarization direction is rotated by 90° irrespective of the initial polarization direction and the angular orientation of the combination.

Another approach for rotating a polarization state is to use a polarization rotation unit comprising an optically active material. These materials have the property of rotating the polarization direction dependent on the distance the light ray propagates within the respective material. By using active materials of different thicknesses, it is possible to vary the angle of rotation.

It is also possible to use a liquid crystal as an active material. Certain liquid crystals make it possible to rotate the polarization direction depending on the strength of an electric field to which the crystal is exposed. This makes it possible to rotate the polarization direction between the two polarization manipulators continuously and merely by changing the voltage applied to the liquid crystal of the first polarization manipulator.

Alternatively, the polarization rotation unit may comprise a polarization modulator that may, for example, exploit the magneto-optic or the electro-optic effect. Such modulators are available as Faraday, Kerr or Pockels rotators, for example.

The polarization rotation unit may be located in the immediate proximity of a first optical raster element that modifies the angular distribution of the light emitted by the light source. Proximity is understood in this sense to include a range of several centimeters, particularly of up to 5 cm. At this position, the cross section of the projection light beam is very small so that the polarization rotation unit may be small, too.

Alternatively, the polarization rotation unit may be located in or in close proximity of a pupil plane of the illumination system.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 shows a perspective and simplified view of a projection exposure apparatus comprising an illumination system;

FIG. 2 shows a simplified meridional section through the illumination system of FIG. 1 showing various possible positions for a polarization rotation unit;

FIG. 3a shows a pupil plane with a low sigma illumination setting with the polarization rotating unit deactivated;

FIG. 3b shows the pupil plane from FIG. 3a with the polarization rotating unit activated such that the polarization direction is rotated by 90°;

FIG. 3c shows the pupil plane from FIG. 3a, but with the polarization rotating unit activated such that the polarization direction is rotated by an angle close to 44°;

FIG. 4 shows a simplified meridional section through an illumination system according to second embodiment in which the polarization rotation unit is located in the vicinity of a first pupil plane;

FIG. 5 shows a simplified meridional section through an illumination system according to a third embodiment in which the polarization rotation unit is located in a second pupil plane.

DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows a perspective and highly simplified view of an exemplary projection exposure apparatus. The projection exposure apparatus, which is denoted in its entirety by PEA, comprises an illumination system 10 that produces a projection light bundle and will be further explained with reference to the following FIG. 2. The projection light bundle illuminates, in the embodiment shown, a narrow rectangular light field LF on a mask M containing minute structures ST. The structures ST within the light field LF are imaged onto a light sensitive layer, for example a photoresist, which is deposited on a substrate. The substrate, which is realized in this embodiment as a silicon wafer W, is arranged on a stage in an image plane of a projection lens PL. The projection lens usually comprises a plurality of lenses and often also several plane or curved mirrors. Since the projection lens PL has a magnification of less than 1, a minified image LF' of the structures ST within the light field LF is projected onto the wafer W.

During the projection, the mask M and the wafer W are moved along a scan direction along the Y-axis. The ratio between the velocities of the mask M and the wafer W is equal to the magnification of the projection lens PL. If the projection lens PL inverts the image, the mask M and the wafer W move in opposite directions, as this is indicated in FIG. 1 by arrows A1 and A2. Thus the light field LF scans over the mask M so that also larger structured areas on the mask M can be projected continuously onto the photoresist. Such a type of projection exposure apparatus is often referred to as "scanner". However, the present invention may also be applied to projection exposure apparatuses of the "stepper" type in which there is no movement of the mask and the wafer during the projection.

FIG. 2 shows a meridional section of the illumination system 10 according to a first embodiment. For the sake of clarity, the illustration shown in FIG. 2 is considerably simplified and not to scale. This particularly implies that different optical units are represented by very few optical elements only. In reality, these units may comprise significantly more lenses and other optical elements.

The illumination system 10 comprises a housing 12 and a light source that is, in the embodiment shown, realized as an excimer laser 14. The excimer laser 14 emits projection light that has a wavelength in the deep ultraviolet (DUV) spectral range, for example 193 nm. Other wavelengths, for example 248 nm or 157 nm, are also considered. The projection light emitted by the laser 14 is homogenously linearly polarized. A light wave is referred to as linearly polarized if its electric field vector oscillates in a fixed plane of vibration. The polarization is homogenous since all light rays emitted by the laser 14 have the same polarization direction.

The projection light emitted by the excimer laser 14 enters a beam expansion unit 16 in which the light bundle is expanded. After passing through the beam expansion unit 16, the projection light impinges on a first optical raster element 18. The first optical raster element 18 is received in a holder 19 so that it can easily be replaced by other optical raster elements having different properties. The first optical raster element 18 comprises, in the embodiment shown, one or more diffraction gratings that deflect each incident ray such that a divergence is introduced. This means that at each location on the optical raster element 18, light is diffracted within a certain range of angles. This range may extend, for example, from -3° to +3°. In FIG. 2 this is schematically represented for an axial ray that is split into two diverging rays 20, 22. The first optical raster element 18 thus modifies the angular distribution of the projection light and influences the local intensity distribution in a subsequent pupil plane.

The first optical raster element 18 can also be replaced by any other kind of optical raster element, for example a micro-lens array with conventional micro-lenses or micro-lenses formed by Fresnel zone plates. Further examples for optical raster elements that are suitable for this purpose are given in the US 6 285 443 A. The full disclosure of the US 6 285 443 A is incorporated herein by reference.

Immediately behind the first optical raster element a polarization rotation unit PRU is located. The polarization rotation unit PRU comprises, in the embodiment shown, a rotational holder RH and a half-wave plate HWP. A half-wave plate has the property of rotating the polarization direction by an angle 2β, wherein β is the angle between a principal axis of the half-wave plate and the polarization direction of incident light. The half-wave plate HWP is made of birefringent material, for example intrinsically birefringent material such as quartz, calcite (CaF_2) or magnesium fluoride (MgF_2). Birefringence may also be induced or increased by mechanical stress applied to the material. The half-wave plate HWP may be of the multi-order type in which the phase difference between normal polarization directions amounts to an uneven multiple of 180°.

The expanded projection light beam has a small cross section at this position of the half-wave plate HWP. For example, the cross section may have an area of 2x2 cm^2. Therefore the half-wave plate HWP can have small lateral dimensions as well. This facilitates the fabrication of the half-wave plate.

The rotational holder RH may be configured such that the half-wave plate HWP can be replaced by another optical element, for example a Hanle depolarizer. This is explained further below.

If the half-wave plate HWP is oriented such that its principal axes are always perpendicular to an optical axis OA of the illumination system 10, it is possible, by rotating the half-wave plate HWP around the optical axis OA, to rotate the polarization direction of incident light by an arbitrary angle.

To this end, the rotational holder RH makes it possible to rotate the half-wave plate HWP by discrete or, more preferably, by arbitrary angles around the optical axis OA. Since holders of this kind are generally known in the art as such, its construction will not be explained in further detail here. An additional electrically driven actuator A (indicated in FIG. 2 in dotted lines) may be provided that rotates the HWP in the rotational holder RH upon an appropriate control signal. The function of the half-wave plate HWP will be explained further below with reference to FIGS. 3a, 3b and 3c.

The first optical raster element 18 is positioned in an object plane 24 of a first objective 26 that is indicated by a zoom lens group 25 and a pair 27 of axicon elements 27a, 27b having opposing conical faces. If both axicon elements 27a, 27b are in contact, the axicon group has no refractive effect. If both elements 27a, 27b are moved apart, the spacing between the axicon elements 27a, 27b results in a shift of light energy radially outward. Since the axicon group is known as such, it will not be explained here in further detail.

Reference numeral 28 denotes an exit pupil plane of the first objective 26. In or in close proximity to the exit pupil plane 28 an exchange holder 29 for different optical components is located. These optical components can, when inserted into the exchange holder 29, modify certain optical properties of the light in the pupil plane 28, for example the spacial polarization distribution. An example for an optical component that may, in a certain mode of operation, be inserted into the exchange holder 29, is described in US 6 392 800 B2 whose full disclosure is incorporated herein by reference.

A second optical raster element 30 is also positioned in or in close proximity to the pupil plane 28 of the first objective 26. The second optical raster 30 introduces a divergence for each point and influences the geometry of the light field on the mask M. If the light field has the shape of a slit as is shown in FIG. 1, the numerical aperture of the second optical raster element 30 may be in the range from 0,28 to 0,35 in the X-direction and in the range from 0,07 to 0,09 in the Y-direction.

The second optical raster 30 may, similar to the first optical raster element 18, be realized as a diffractive optical element, a micro-lens array or a combination of both. The divergence introduced by the second optical raster component 30 is schematically represented in FIG. 2 by divergent rays 20a, 20b and 22a, 22b for the impinging rays 20 and 22.

The diverging rays 20a, 20b and 22a, 22b enter a second objective 32 that is represented in FIG. 2 by a single condenser lens 32. The second objective 32 is arranged within the illumination system 10 such that its entrance pupil plane coincides with the exit pupil plane 28 of the first objective 26. The image plane 34 of the second objective 32 is a field plane in which an adjustable stop 38 is positioned. The stop 38 ensures sharp edges of the illuminated light field LF along the scan direction Y. The stop 38 may make it possible to adapt the lateral dimension of the light field LF in the Y-direction by a plurality of movable blades, as is disclosed in EP 0 952 491 A2. The full disclosure of this document is incorporated herein. By selectively moving the blades it is possible to ensure a constant light intensity during the scan movement for each point in the mask M.

In order to achieve sharp edges at least along the Y-direction, a third objective 42 is arranged along the optical axis OA of the illumination system 10. The third objective 42 has an object plane that coincides with the image plane 34 of the second objective 32. In an image plane 46 of the third objective 42 the mask M can be positioned using a mask stage (not shown). The third objective 42 is indicated by only three lenses and a plane mirror 43 that tilts the optical axis OA by 90°. However, from the foregoing it becomes clear that the third objective 42 may comprise considerably more optical elements than indicated in FIG. 2.

In the following the function of the half-wave plate HWP will be explained further with reference to FIGS. 3a, 3b and 3c.

FIG. 3a shows the intensity distribution in the exit pupil plane 28 in a first mode of operation. In this mode, both axicon elements 27a, 27b contact each other and the half-wave plate HWP is removed from the rotational holder RH. Apart from that, a first raster element 18 is inserted into the exchange holder 19 that diffracts the light by a small quasi-continuous range of angles. This results in a intensity distribution in the exit pupil plane 28 in which only a central spot having the shape of a disk 48 is illuminated. Such an illumination setting is often referred to as a "conventional low sigma setting" because the diameter of the disk is comparatively small. For example, the diameter of the disk 48 may be in the range between approximately 5% to 30% of the diameter of a fully illuminated pupil.

Since the optical elements preceding the exit pupil plane 28 do not alter the state of polarization, the light within the illuminated disk 48 is still in its initial linear state of polarization. Thus the initial polarization direction PD_i of the light emitted by the laser 14 is maintained. In FIG. 3a the polarization direction of the projection light within the disk 48 is indicated by parallel lines.

This polarization direction PD_i may be particularly suitable for the projection of certain masks, for example of a mask in which structures having a certain orientation predominate.

However, if another mask shall be projected onto the wafer W, another polarization direction may result in better imaging properties. For example, a mask could be used in which structures are predominant that have another orientation. In such a case the have-wave plate HWP is inserted into the rotational holder RH. The half-wave plate HWP is inserted in such a orientation (or inserted in an arbitrary orientation and then appropriately rotated) that it rotates the polarization direction by the desired angle.

In FIG. 3b it is assumed that the half-wave plate HWP is oriented such that one of its principal axes forms an angle of 45° between the initial direction of polarization PD_i. This results in a rotation of the polarization direction by 90°. The rotated polarization direction is indicated in FIG. 3b by PD_r. The intensity distribution in the exit pupil plane 28 as such is not altered by the introduction of the half-wave plate HWP.

Instead of removing and inserting the half-wave plate HWP, it is, of course, also possible to maintain the initial polarization direction PD_i with the half-wave plate HWP in place. To this end, the half-wave plate HWP has to be rotated such that one of its principal axes coincides with the initial polarization direction PD_i.

FIG. 3c shows a representation similar to FIG. 3b. In this mode of opewration, the polarization direction PD_r is not rotated by 90°, but by an angle of approximately 44°. Such an arbitrary angle of rotation can be achieved if the holder makes it possible to hold the half-wave plate HWP in any possible angular position.

If the projection light shall be unpolarized in a further mode of operation, the half-wave plate HWP can be replaced by a depolarizer, for example a Hanle depolarizer, as is known in the art as such. A Hanle depolarizer comprises a first birefringent wedge and a second wedge that does not necessarily have to be made of a birefringent material. The second wedge compensates deviations of the light rays introduced by the first wedge.

FIG. 4 shows another embodiment of the illumination system which is denoted in its entirety by 10'. The illumination system 10' differs from the illumination system 10 according to FIG. 2 in that a polarization rotation unit PRU' is located not in the proximity of the first optical raster element 18, but in or in close proximity to the exit pupil plane 28. However, the diameter of the projection light beam may be, at this position of the polarization rotation unit PRU', as large as 4 cm. This requires larger components for the polarization rotation unit PRU' if compared to the position of the first embodiment shown in FIG. 2.

The polarization rotation unit PRU' comprises in this embodiment a combination ROT of two half-wave plates. These are arranged such that a principal axis of one half-wave plate forms an angle of 45° with a principal axis of the other half-wave plate. Such a combination, which is known as such and usually referred to as a rotator, rotates the polarization direction by 90° independent of the input polarization direction. Therefore the polarization direction may very easily be rotated by 90° irrespective of the initial polarization direction PD_i and the angular orientation of the rotator ROT. An actuator may be provided for automatically inserting the rotator ROT in the path of light on demand.

FIG. 5 shows a further embodiment of the illumination system which is denoted in its entirety by 10''. The illumination system 10'' differs from the illumination systems 10 of FIG. 1 and 2 in that a polarization rotation unit PRU'' is located in or in close proximity to a pupil plane 50 of the third objective 42. The diameter of the projection light beam may be, at this position of the polarization rotation unit PRU'', still larger so that the polarization rotation unit PRU'' has to be larger as well.

In this embodiment the polarization rotation unit PRU'' comprises one or more plates PL made of an optically active material. These materials have the property of rotating the polarization direction dependent on the distance the light ray propagates within the material. By using active materials of different thicknesses, it is possible to vary the angle of rotation. To this end, the polarization rotation unit PRU'' comprises an exchange holder EH that is adapted to receive the plates PL. Instead of providing a set of plates PL having different thicknesses, it is also possible to provide a plurality of thin plates PL of equal or similar thickness that can be stacked together in the exchange holder EH. The overall thickness can then be varied by adding or removing single plates PL from the stack.

With some optical active materials, the angle of rotation does not only depend on the length of the path within the material, but also on an electric field to which the liquid crystal is exposed. This approach of controlling the angle of rotation is exploited, for example, in commonplace liquid crystal displays (LCD).

The polarization rotation unit PRU'' may therefore contain, in addition to a suitable liquid crystal, a pair of electrodes so that the liquid crystal may be exposed to a homogeneous electric field. The field strength can be varied by modifying a control voltage using a control unit.

As a further alternative, a polarization rotation unit PRU'' may comprise a polarization modulator that exploits the magneto-optic or the electro-optic effect. Such modulators are available as Faraday, Kerr or Pockels rotators, for example.

As another alternative embodiment, a light mixing rod (not shown) may be positioned between the second objective 32 and the stop 38. The second objective 32 has then to be modified appropriately. For details concerning the light mixing rod reference is made to US 6 285 443 A whose full disclosure is incorporated herein.

It is to be understood that the foregoing examples and alternatives for polarization rotation units may also be employed in any one of the embodiments described before.

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 claims, and equivalents thereof.

CLAIMS

1. An illumination system for a microlithographic projection exposure apparatus (PEA), comprising:

a) a light source (14) emitting linearly polarized light having a fixed polarization direction (PD_i),

b) a polarization rotation unit (PRU, PRU', PRU'') that is configured to rotate the polarization direction on demand by a rotational angle $\alpha \neq 0°$.

2. The illumination system of claim 1, wherein the polarization rotation unit (PRU, PRU'') is configured to rotate the polarization direction by at least two different rotational angles.

3. The illumination system of claim 2, wherein the polarization rotation unit (PRU, PRU', PRU'') is configured to rotate the polarization direction by an arbitrary rotational angle.

4. The illumination system of any of the preceding claims, wherein the polarization rotation unit (PRU) comprises a half-wave plate (HWP).

5. The illumination system of claim 4, wherein the polarization rotation unit (PRU) comprises a holder

(RH) located in the path of light and receiving the half-wave plate (HWP).

6. The illumination system of claim 5, wherein the half-wave plate (HWP) is detachably received in the holder (RH).

7. The illumination system of any of claims 4 to 6, wherein the holder (RH) is configured to receive the half-wave plate (HWP) in at least two different angular positions.

8. The illumination system of claim 7, wherein the holder (RH) is configured to rotate the half-wave plate (HWP) around an axis that coincides with an optical axis (OA) of the illumination system (10) or is aligned parallel thereto.

9. The illumination system of claim 8, comprising an actuator (A) for rotating the half-wave plate (HWO) in the holder (RH).

10. The illumination system of any of claims 4 to 9, wherein the half-wave (HWP) plate is made of an intrinsically birefringent material.

11. The illumination system of any of claims 4 to 9, wherein the half-wave plate (HWP) is made of mate-

rial in which birefringence is induced by mechanical stress.

12. The illumination system of claim 2, wherein the polarization rotation unit (PRU') comprises a first half-wave plate and a second half-wave plate that are arranged such that a principal axis of the first half-wave plate forms an angle of 45° with a principal axis of the second half-wave plate.

13. The illumination system of claim 12, wherein the polarization rotation unit (PRU') comprises an exchange holder (29) that is configured to detachably receive the first and second half-wave plates upon insertion of same in the exchange holder.

14. The illumination system of any of claims 1 to 3, wherein the polarization rotation unit (PRU'') comprises an optically active material.

15. The illumination system of claim 14, wherein the polarization rotation unit (PRU'') comprises a plurality of plates (PL) that are each made of an optically active material, wherein each plate (PL) rotates the polarization direction by substantially the same rotational angle.

16. The illumination system of any of claims 14 to 15, wherein the optically active material is a liquid crystal.

17. The illumination system of claim 14, wherein the polarization rotation unit (PRU'') comprises an exchange holder (EH) that is configured to detachably receive the optically active material in the exchange holder (EH).

18. The illumination system of any of claims 1 to 3, wherein the polarization rotation unit comprises a polarization modulator.

19. The illumination system of claim 18, wherein the polarization modulator exploits the magneto-optic effect or the electro-optic effect.

20. The illumination system any of claims 18 to 19, wherein the polarization rotation unit comprises an exchange holder that is configured to detachably receive the polarization modulator in the exchange holder.

21. The illumination system of any of the preceding claims, wherein the polarization rotation unit (PRU) is located in the immediate proximity of a first optical raster element (18) that modifies the angular distribution of the light emitted by the light source (14).

22. The illumination system claim 21, wherein the polarization rotation unit (PRU) is located immediately in front of or immediately behind the first optical raster element (18).

23. The illumination system of any of claims 21 to 22, wherein the optical raster element (18) is a diffractive optical element.

24. The illumination system of any of claims 1 to 20, wherein the polarization rotation unit (PRU'; PRU'') is located in or in close proximity of a pupil plane (28; 50) of the illumination system (10'; 10'').

25. The illumination system of claim 24, wherein the polarization rotation unit (PRU') is located in or in close proximity of an exit pupil plane (28) of a first optical unit (26) that is arranged between the first optical raster element (18) and a second optical raster element (30).

26. The illumination system of claim 25, wherein the first optical unit (26) comprises at least one pupil forming element (25, 27) that modifies an intensity distribution in the exit pupil.

27. The illumination system of claim 26, wherein the pupil forming element comprises an optical zoom unit (25).

28. The illumination system of any of claims 26 to 27, wherein the pupil forming element comprises a pair (27) of axicon elements (27a, 27b).

29. The illumination system of any of claims 1 to 20, wherein the polarization rotation (PRU'') unit is located in or in close proximity of a pupil plane (50) of a second optical unit (42) that images a field plane (34) into a mask plane (46), said field plane being conjugated to the exit pupil (28) of the first optical unit (26) by Fourier transformation.

30. The illumination system of claim 29, wherein a field stop (38) is located in the field plane.

31. The illumination system of any of the preceding claims, wherein the illumination system (10) comprises at least one plane mirror (43).

32. A projection exposure apparatus comprising:

a) an illumination system (10; 19'; 10'') according to any of the preceding claims,

b) a mask plane in which a mask (M) can be arranged,

c) a projection lens (PL) imaging the mask plane on an image plane.

33. The projection exposure apparatus of claim 32, wherein the projection lens (PL) comprises at least one plane mirror.

34. A microlithographic method of fabricating a micro-structured device, comprising the following steps:

a) providing a substrate (W) supporting a light sensitive layer;

b) providing a mask (M) containing structures (ST) to be imaged onto the light sensitive layer;

c) providing an illumination system (10; 10', 10'') comprising a light source (14) emitting linearly polarized light having a fixed polarization direction (PD_i),

d) rotating the polarization direction (PD_i) by a rotational angle $\alpha \neq 0°$;

e) projecting at least a part of the mask (M) onto the light sensitive layer using a projection lens (PL).

35. The method of claim 34, wherein a disk shaped area (48) is illuminated in a pupil plane (28) of the illumination system.

36. The method of claim 35, wherein the area (48) has a diameter that is less than 30% of the maximum diameter that can be illuminated in the pupil plane.

37. A microlithographic method of fabricating a microstructured device, comprising the following steps:

a) providing a substrate (W) supporting a light sensitive layer;

b) providing a mask (M) containing structures (ST) to be imaged onto the light sensitive layer;

c) providing an illumination system (10; 10'; 10'') according to any one of claims 1 to 31;

d) projecting at least a part of the mask (M) onto the light sensitive layer using a projection lens (PL).

38. A microstructured device, characterized in that it is fabricated according to the method of any of claims 34 to 37.

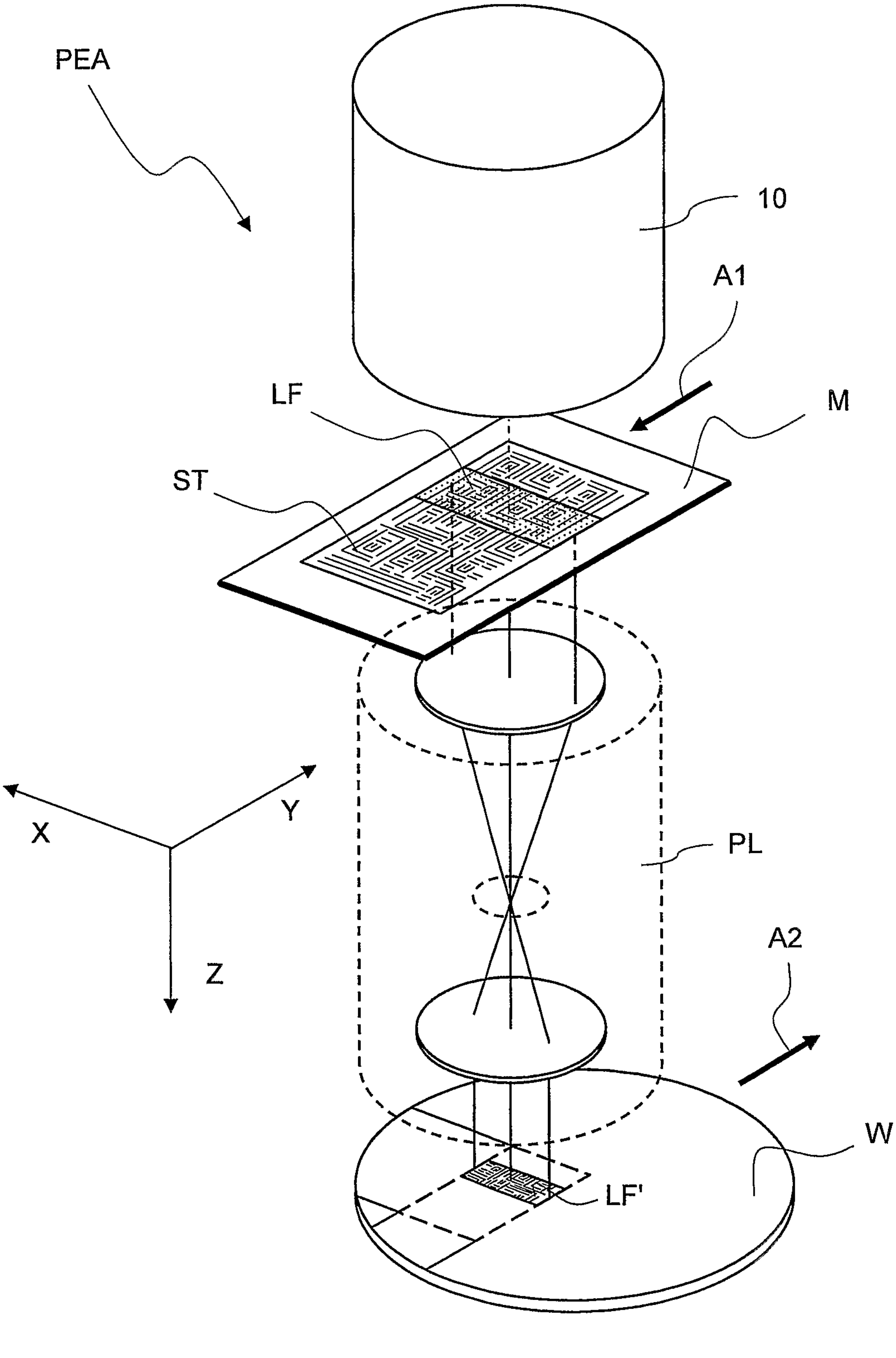

Fig. 1

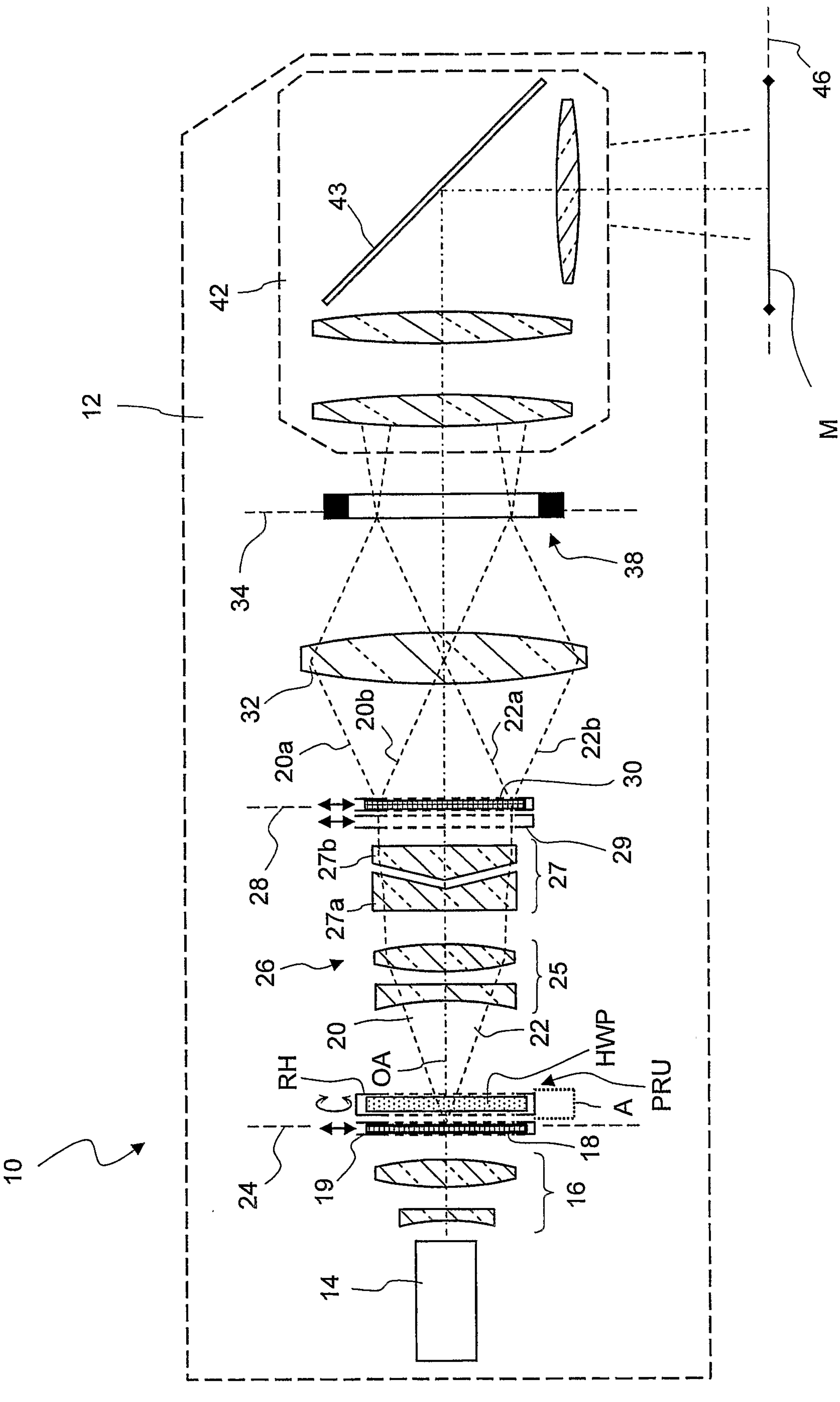
10
12
14
16
18
19
20
20a
20b
22
22a
22b
24
25
26
27
27a
27b
28
29
30
32
34
38
42
43
46
M
RH
OA
HWP
PRU
A

Fig. 2

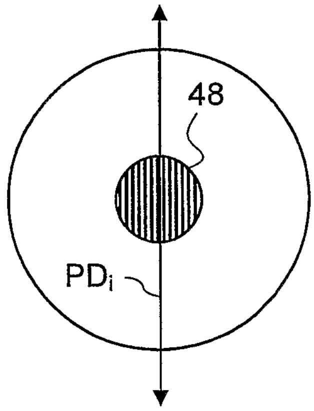

Fig. 3a

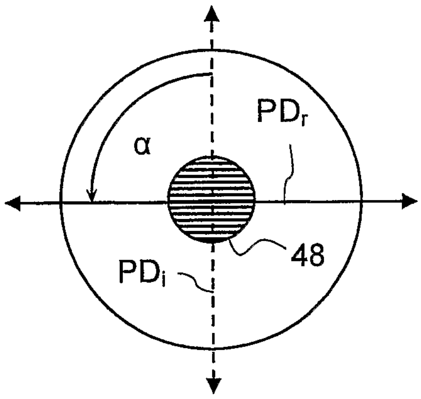

Fig. 3b

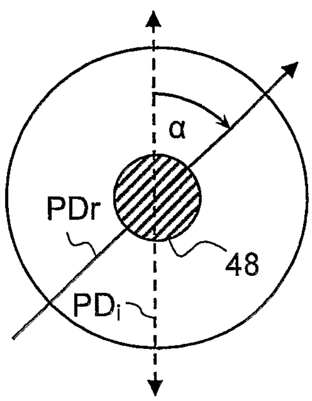

Fig. 3c

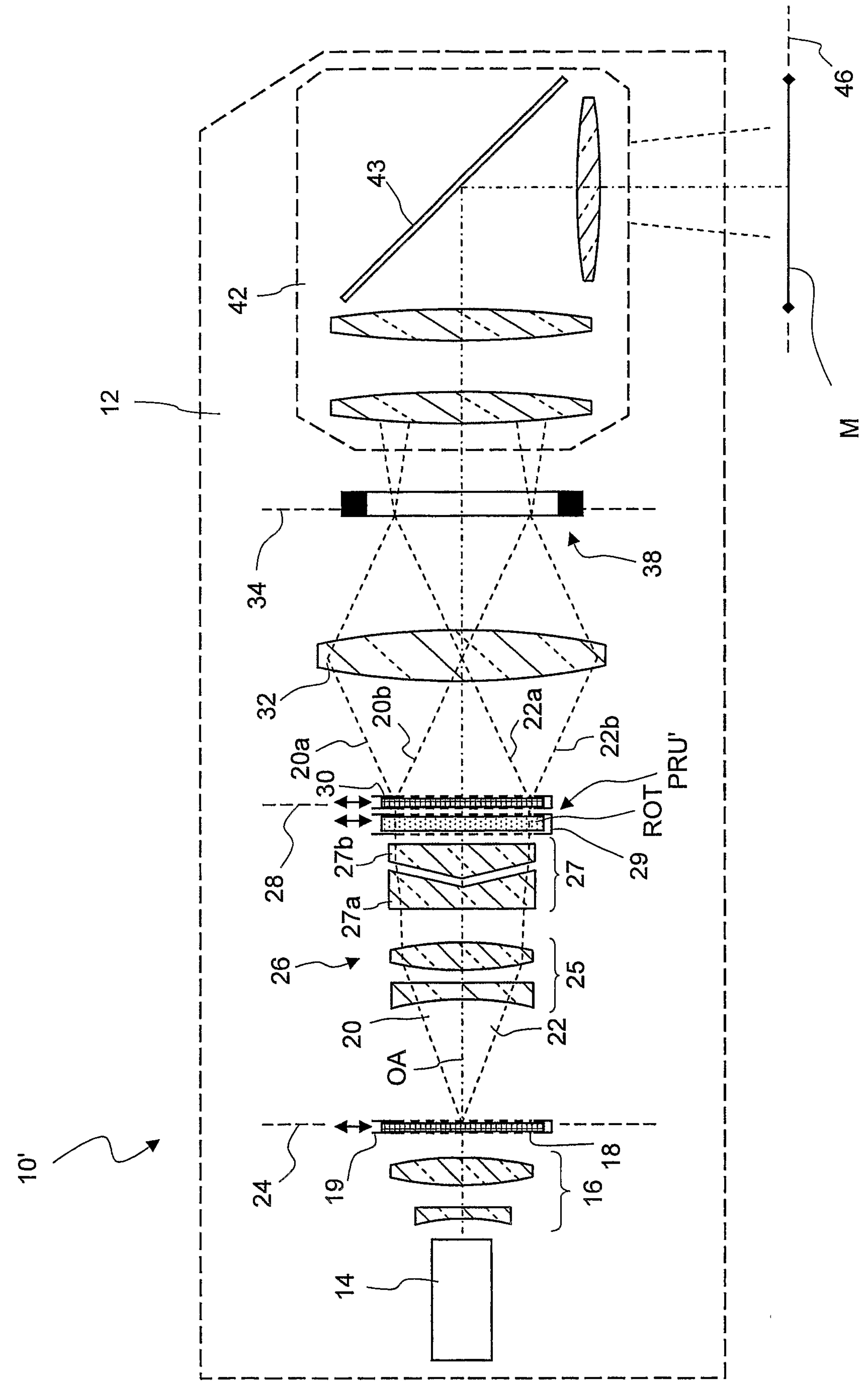
10'
12
14
16
18
19
20
20a
20b
22
22a
22b
24
25
26
27
27a
27b
28
29
30
32
34
38
42
43
46
M
OA
ROT
PRU'

Fig. 4

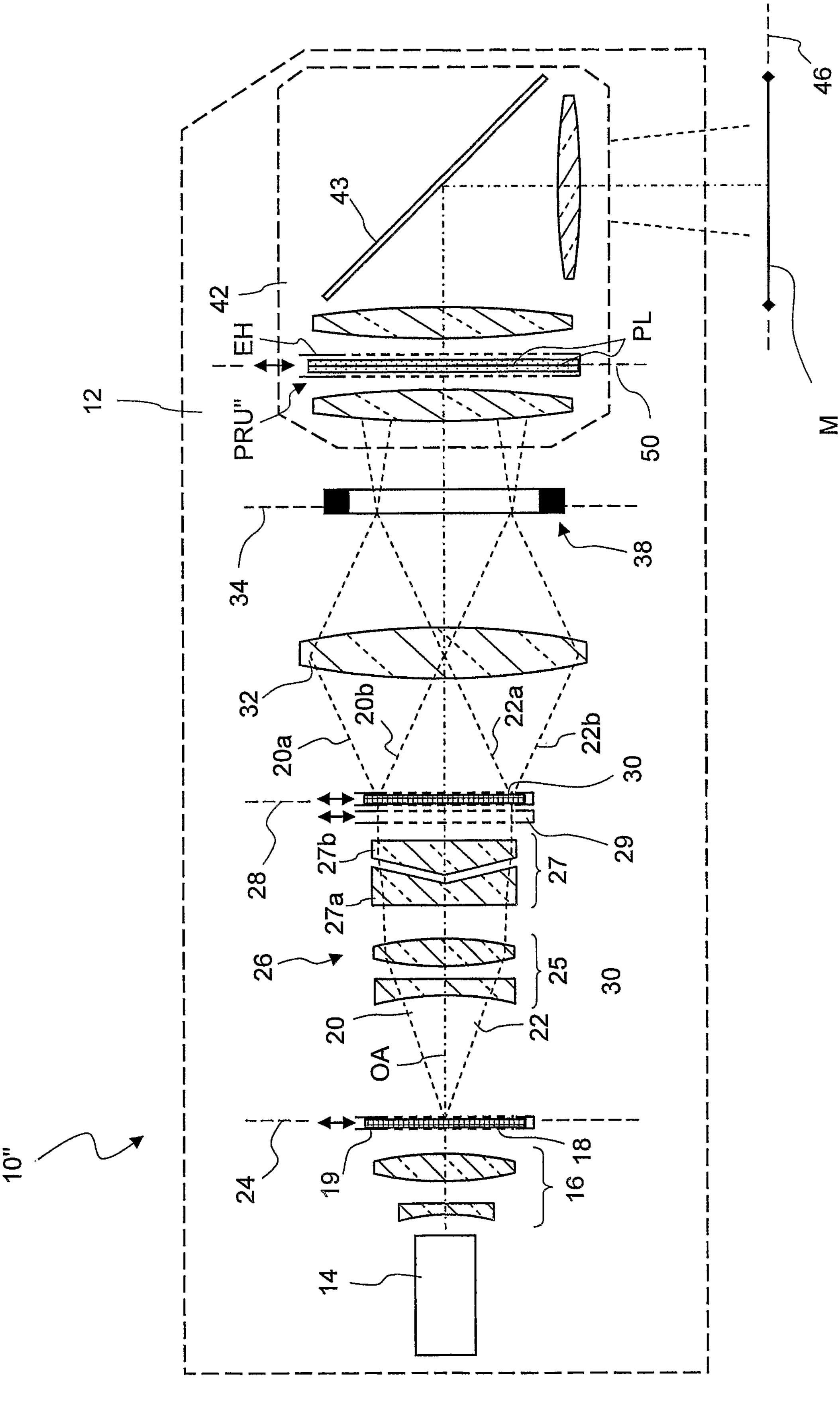
10"
12
14
16
18
19
20
20a
20b
22
22a
22b
24
25
26
27
27a
27b
28
29
30
30
32
34
38
42
43
46
50
OA
EH
PL
PRU"
M

Fig. 5