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(54) Title: MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS AND METHOD OF CORRECTING AN ABERRATION IN SUCH AN APPARATUS

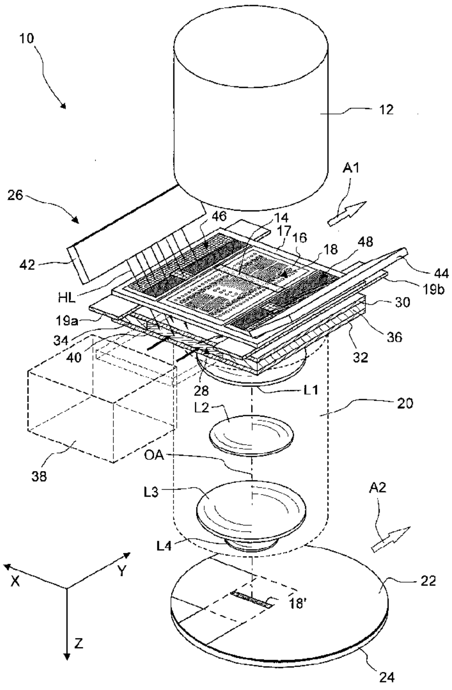

Fig. 1

(57) Abstract: A microlithographic projection exposure apparatus comprises a mask stage (19a, 19b) configured to displace a mask (16) along a scan direction (Y), a projection objective (20) and a substrate stage (25) that is configured to move a substrate (24) supporting a light sensitive layer (22) synchronously with the mask (16). A correction device (26) comprises a fluid supply unit (38) that is configured to produce a fluid flow (40) through which the projection light (PL) passes. The fluid flow (40) moves, during a scan exposure of the light sensitive surface (22), parallel to and with the same velocity as the mask (16). The correction device further comprises a fluid heating device (42, 44, 46, 48) that is configured to produce a variable temperature distribution in the fluid flow (40) so that also the temperature distribution moves parallel to and with the same velocity as the mask (16).

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MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS AND METHOD OF CORRECTING AN ABERRATION IN SUCH AN APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention generally relates to a microlithographic projection exposure apparatus comprising a correction device that is capable of correcting a field-dependent aberration, and in particular an aberration that is caused a deformation or another imperfection of a mask or a substrate. The invention further relates to a method of correcting such an aberration.

2. Description of Related Art

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 ultraviolet light. 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.

A projection exposure apparatus typically comprises an illumination system, a mask alignment stage for aligning the mask, a projection objective (often simply referred to as "the lens") and a wafer alignment stage for aligning the wafer coated with the photoresist. The illumination 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 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 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 magnification β of the projection lens, for which usually $|\beta|<1$ holds, for example $|\beta|= 1/4$ or $|\beta|=1/100$.

One of the essential aims in the development of projection exposure apparatus is to be able to lithographically define structures with smaller and smaller dimensions on the wafer. Small structures lead to an increased output of the manufacturing process and also to a high integration density. This, in turn, has usually a favorable effect on the performance of the produced microstructured components.

The minimum size of the structures that can be lithographically defined is approximately proportional to the wavelength of the projection light. Therefore the manufacturers of such apparatus strive to use projection light having shorter and shorter wavelengths. The shortest wavelengths currently used are 365 nm, 248 nm and 193 nm and thus lie in the deep (DUV) or vacuum (VUV) ultraviolet spectral range.

The correction of aberrations is becoming increasingly important for projection objectives designed for operating wavelengths in the DUV and VUV spectral range. Different types of aberrations usually require different correction measures.

The correction of field independent and rotationally symmetric aberrations is comparatively straightforward. A field independent aberration is referred to as being rotationally symmetric if it is invariant against a rotation of the projection objective around its optical axis. The term wavefront deformation refers to the deviation of a wavefront from an ideal aberration-free wavefront. Rotationally symmetric aberrations can be corrected, for example, at least partially by moving individual optical elements along the optical axis.

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

In order to correct rotationally asymmetric aberrations, 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 aberrations are at least partially corrected. A more complex type of such a wavefront correction device is disclosed in US 2010/0128367 A1.

US 7,830,611 B2 discloses a similar wavefront 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 Zernike polynomials of higher radial order, such as Z_{19}, Z_{30}, Z_{36}, Z_{40} or Z_{64}.

US 2010/0201958 A1 and US 2009/0257032 A1 disclose a wavefront correction device that comprises two glass plates that are separated from each other by a liquid. However, in contrast to the device described in the aforementioned US 7,830,611 B2, a corrective effect on the wavefront is not obtained by deforming the glass plates, but by changing their refractive index locally. To this end one of the two glass plates is provided with heating wires that extend over a surface through which projection light passes. With the help of the heating wires a temperature distribution inside the glass plate can be produced that causes, via the dependency dn/dT of the refractive index n on the temperature T, the desired distribution of the refractive index.

WO 2011/116792 A1 and EP 1 524 558 A1 disclose a wavefront correction device in which a plurality of fluid flows emerging from a corresponding number of fluid outlet apertures enter a space through which projection light propagates during operation of the projection exposure apparatus. A temperature controller, which may comprise heat dissipating members that are arranged at the outside of channels walls, sets the temperature comprising individually for each fluid flow. The temperature distribution is determined such that optical path length differences caused by the temperature distribution correct wavefront errors. An advantage of this prior art wavefront correction devices is that it is able to correct also wavefront deformations which change very quickly, for example during a single scan cycle. Since this correction device is arranged in the pupil plane of the projection objective, it has a field-independent effect.

WO 2013/044936 A1 discloses a wavefront correction device in which a plurality of heating light beams are directed towards a circumferential rim surface of a refractive optical element. After entering the refractive optical element, the heating light beams are partially absorbed inside the element. In this manner almost arbitrary temperature distributions with steep temperature gradients can be produced inside the refractive optical element, but without a need to arrange heating wires in the projection light path that absorb, reflect, diffract and/or scatter projection light to an albeit small, but not negligible extent.

New lithographic technologies such as multiple patterning and spacering have significantly tightened the specifications with respect to the axial and lateral positioning of the mask and the substrate. Only if the image of a structure is located exactly at the desired axial position (i.e. resist surface) and the desired lateral position, these more sophisticated lithographic technologies can be successfully carried out.

Since the mask absorbs a portion of the projection light, the temperature distribution in the mask changes during the operation of the apparatus. Since changes of the temperature distribution generally result in deformations of the mask, the structures to be imaged may not be located any more in the object plane of the objective, or may be laterally offset. On the other hand, the thickness of the resist applied on the substrate may slightly vary. Since the depth of focus of the projection objective is usually very small, the top surface of the resist may be locally out of focus, which results in a blurred image.

There is therefore a need to be able to correct aberrations that are associated with the mask and substrate as such. Ideally it should be possible to modify the optical wavefronts emerging from a point on the mask while the point moves through the illuminated field. Since each point of a mask and/or the resist may require a different correction, a correction device should be able to correct very efficiently and rapidly field-dependent aberrations.

SUMMARY OF THE INVENTION

a) First aspect

It is therefore an object of the present invention to provide a microlithographic projection exposure apparatus comprising a correction device which is capable of correcting rapidly changing field-dependent aberrations that are caused by the moving mask or the moving substrate.

This object is achieved, in accordance with the present invention, by a microlithographic projection exposure apparatus comprising a primary illumination system configured to illuminate a mask, which contains a pattern, with projection light. The apparatus further comprises a mask stage configured to displace a mask along a scan direction, and a projection objective configured to image a field, which is illuminated on the mask with the projection light while the mask is displaced along the scan direction, on a light sensitive surface. A substrate stage is configured to move a substrate supporting the light sensitive layer synchronously with the mask. A correction device is provided that comprises a fluid supply unit that is configured to produce a fluid flow through which the projection light passes. The fluid flow moves, during a scan exposure of the light sensitive surface, parallel to and with the same velocity as the mask. The correction device further comprises a fluid heating device that is configured to produce a variable temperature distribution in the fluid flow so that also the temperature distribution moves at least substantially parallel to and with the same velocity as the mask.

The invention is based on the perception that rapidly changing aberrations can best be corrected by quickly varying the temperature distribution in a fluid. If the aberrations are caused by a moving mask or a moving substrate, a very good correction can be achieved if also the fluid with the variable temperature distribution moves parallel to and with the same velocity as the mask.

For correcting field-dependent aberrations of the kind considered here, the fluid flow would ideally be located exactly in a field plane, i.e. the mask plane, the image plane of the projection objective or another plane that is optically conjugate to the mask plane. Since the mask and the image plane are not available because the mask and the light sensitive layer are arranged there, the fluid flow should extend through the projection light path in immediate proximity to a field plane.

More specifically, it is preferred to arrange the mask and the fluid flow at a distance along an optical axis of the projection objective which is smaller than 50 mm and preferably smaller than 25 mm. Preferably the correction device is arranged between the mask and the first optical element of the projection objective on its object side.

In principle the correction device could also be positioned in the immediate vicinity of the image plane of the projection objective. However, the interspace between the projection objective and the resist is usually extremely thin (only a few millimeters at most), and in some apparatus it is filled with an immersion liquid.

In an alternative embodiment the correction device is arranged in an intermediate image plane of the projection objective. Then the fluid flow does not move parallel to and with the same velocity as the mask, but parallel to and with the same velocity as a real image of the mask that is formed in the intermediate image plane.

The fluid may be a liquid such as pure water or a gas.

The fluid heating device may comprise a heating light illumination system that is configured to variably illuminate the fluid flow with heating light that does not impinge on the light sensitive surface. The heating light is partially absorbed by the fluid flow and increases its temperature locally at those portions that have been illuminated by the heating light. The resulting temperature distribution is associated, via the dependency dn/dT of the refractive index n on the temperature T, with a refractive index distribution. If the dependency dn/dT is sufficiently large, the refractive index distribution can be used to produce the desired phase variations that are required to correct a wavefront deformation.

The temperature distribution inside the fluid flow is thus produced in a completely contactless manner. Furthermore, this approach results in a very simple construction of the correction device and ensures a better laminarity of the fluid flow, because the fluid supply unit can be designed primarily with a view to achieve an optimum laminarity.

There are different ways in which the fluid flow may be variably illuminated with heating light. In the simplest case the heating light illumination system produces a single fixed irradiance distribution on the fluid flow, but only during certain times that are determined by a control unit.

A wider variety of temperature distributions may be produced in the fluid flow if the heating light illumination system is configured to produce, either intermittently or continuously, a plurality of different spatially varying irradiance distributions on the fluid flow. If the irradiance distributions are continuously varied, the heating light illumination system may be configured to produce an irradiance distribution on the fluid flow which moves parallel to and with the same velocity as the fluid flow. In other words, a certain volume element of the fluid flow is exposed over a certain time to the same irradiance while this volume element moves parallel to and with the same velocity as the mask. Then even temperature distributions with larger temperature differences can be produced on the fluid flow.

Since also for fluids it takes some time until a desired temperature distribution is achieved by the partial absorption of the heating light, the heating light illumination system may be arranged in such a manner that, if seen along the flow direction of the fluid flow, the heating light impinges on the fluid flow at a position which is upstream of the position where the projection light impinges on the fluid flow. Then it is ensured that the volume element in the fluid flow is exposed for a sufficiently long time to the heating light before this volume element enters the space through which the projection light passes.

If the fluid is a gas, for example air, hydrogen, carbon dioxide or sulfur hexafluoride, the fluid flow may freely propagate through a volume, through which projection light passes, without a need for any guide structures. However, in that case it is often difficult to ensure a sufficient laminarity of the gas flow. Furthermore, such a free gas flow tends to expand, which results in undesired density variations which will affect also the refractive index distribution.

For that reason it will generally be expedient, and if the fluid is a liquid even mandatory, to have a wavefront correction device that comprises a fluid channel that is configured to guide the fluid flow along a flow direction. The channel is defined by a channel wall, wherein at least a first portion of the channel wall is transparent for the projection light, and wherein at least a second portion of the channel wall, which preferably will, but does not necessarily have to be distinct from the first portion, is transparent for the heating light. Furthermore, the fluid channel is arranged in a beam path of the projection light such that a) the projection light passes through the first portion of the channel wall and b) the heating light passes through the second portion of the channel wall and the fluid flow.

In some embodiments the heating light illumination system comprises a heating light source and a spatial light modulator that is arranged in a heating light path between the heating light source and the fluid flow. The spatial light modulator is used to produce different spatially varying irradiance distributions on the fluid flow.

To this end the spatial light modulator may comprise an array of mirrors or an LCD panel, for example. In other embodiments the spatial light modulator comprises a transmission filter having a transmission distribution that is non-uniform, and a transport device that is configured to displace the transmission filter while the mask is displaced along the scan direction. With such a moving transmission filter it is possible to produce a heating light irradiance distribution on the fluid flow that moves parallel to and with the same velocity as the fluid flow and thus as the mask.

A perfect synchronization is achieved if the transmission filter is formed by a portion of the mask or by a filter element that is supported by a mask carrier supporting the mask.

Then the mask transport device is formed by the mask stage itself, and thus an additional transport device and control means for synchronizing the movements of the transmission filter and the mask can be completely dispensed with.

In other embodiments the heating light illumination system comprises a plurality of individual heating light sources that are configured to be controlled independently from each other. The control of a spatial modulator comprising a plurality of pixel elements such as micro-mirrors or liquid crystals is thus replaced by the control of the individual heating light sources.

If the individual heating light sources are arranged in a two-dimensional array, very complex and almost arbitrary temperature distributions can be produced inside the fluid flow. This particularly applies if the array is arranged at least substantially parallel to the fluid flow, and in particular between the mask and the fluid flow.

The fluid supply unit may comprise a temperature controller that is configured to set the temperature of the fluid flow in such a way that the fluid flow, after being heated by the heating light in the projection light, does not affect the heat balance of the correction device. In other words, the net amount of heat produced by the partial absorption of the heating light and the projection light is compensated by a cooling of the fluid which is emitted by the fluid supply unit. This increases the effectiveness on the one hand and reduces problems that are associated with a correction device that produces a varying amount of heat during the operation of the apparatus.

In many cases it will be expedient if the projection light has a central projection light wavelength and the heating light has a central heating light wavelength, wherein the fluid has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength. Preferably the coefficients differ by a factor of more than 2, and more preferably by more than 10. Then the heating light is more strongly absorbed by the fluid than the projection light, for which the transmission should be as large as possible.

Instead of producing a variable temperature distribution in the fluid flow with the help of a heating light illumination system, the correction device may comprise a plurality of fluid outlet apertures. The fluid heating device then comprises a plurality of temperature control units each being configured to change the temperature of the fluid emerging from the fluid outlet apertures in response to a control signal. The fluid emerging from the fluid outlet apertures may be considered as sub-flows that combine to form the fluid flow having a two-dimensional or even three-dimensional temperature distribution.

Each temperature control unit may be connected to a first reservoir filled with fluid having a first temperature and to a second reservoir filled with fluid having a second temperature which is higher than the first temperature. Each temperature control unit may comprise a fluid mixing device configured to mix fluid from the first reservoir and fluid from the second reservoir to obtain a mixed fluid that has a temperature that is between the first temperature and the second temperature. Such a fluid mixing device is capable of changing the temperature very quickly, because the desired target temperature is not produced by heating or cooling a fluid, but by mixing the fluids having different temperatures.

Other means to individually set the temperature of a plurality of fluid sub-flows can be gleaned from WO 2011/116792 A1 which has already been mentioned above. The full disclosure of this earlier application is incorporated by reference.

Subject of the invention is also a method of correcting an aberration in a microlithographic projection exposure apparatus. The method comprises the following steps:

a) displacing a mask containing a pattern along a scan direction while a field on the mask is imaged on a light sensitive surface;

b) simultaneously with step a), producing a fluid flow that has a temperature distribution and moves parallel to and with the same velocity as the mask so that projection light, which finally impinges on a light sensitive surface, passes through the fluid flow;

c) varying the temperature distribution of the fluid flow while the mask is displaced.

The fluid flow may be illuminated with heating light that does not impinge on the light sensitive surface.

A transmission filter, which has a transmission distribution that is non-uniform, may be displaced while the mask is displaced along the scan direction. The heating light then impinges on the transmission filter before it impinges on the fluid flow. The transmission filter may be displaced by a mask stage that displaces the mask along the scan direction.

A plurality of individual heating light sources may direct heating light beams on the fluid flow. The plurality of heating light sources may be controlled such that a moving irradiance distribution is produced on the fluid flow.

Preferably the moving irradiance distribution has a direction and a velocity which coincide with a direction and velocity, respectively, of the mask.

The temperature distribution of the fluid may be controlled in such a way that the fluid flow does not affect the heat balance of the correction device.

b) Second aspect

It is another object of the present invention to provide a microlithographic projection exposure apparatus comprising a correction device which is capable of correcting quickly changing aberrations, and in particular quickly changing rotationally asymmetric wavefront deformations. Nevertheless the device shall have a simple structure and shall not significantly increase the amount of scattered light.

This object is achieved by a microlithographic projection exposure apparatus comprising a correction device. The latter comprises a fluid supply unit that is configured to produce a fluid flow through which projection light, which finally impinges on a light sensitive surface, passes. The wavefront correction device further comprises a heating light illumination system that is configured to variably illuminate the fluid flow with heating light, which does not impinge on the light sensitive surface.

This other aspect of the present invention is based on the perception that only the provision of a fluid flow makes it possible to produce varying temperature distributions in a volume, through which the projection light passes, very quickly. The variations of the temperature distribution may even be quick enough to correct wavefront deformations that change during a single scan cycle. This, in turn, makes it possible to correct aberrations that are associated with the scan cycle as such. For example, wavefront deformations may be associated with the pattern contained in the mask, and therefore often display a very strong field-dependency. Then the correction device should be arranged sufficiently close to a mask plane in which the mask is arranged during the scan cycle, or to an optically conjugate intermediate image plane inside a projection objective of the apparatus. In an embodiment the correction device is arranged between the mask and a projection objective that images the mask on the light sensitive layer.

However, instead of producing the desired temperature distribution inside the fluid flow by using a plurality of fluid outlet apertures emitting individually heated fluid flows, as this is known in the art, it is proposed to produce the desired temperature distribution inside the fluid flow by variably illuminating the fluid flow with heating light. The heating light is partially absorbed by the fluid flow and increases its temperature locally at those portions that have been illuminated by the heating light. The resulting temperature distribution is associated, via the dependency dn/dT of the refractive index n on the temperature T, with a refractive index distribution. If the dependency dn/dT is sufficiently large, the refractive index distribution can be used to produce the desired phase variations that are required to correct a wavefront deformation.

The temperature distribution inside the fluid flow is thus produced in a completely contactless manner. Furthermore, this approach results in a very simple construction of the correction device and ensures a better laminarity of the fluid flow, because the fluid supply unit can be designed primarily with a view to achieve an optimum laminarity.

It should be noted in this context that the term "correction" is used here in a very broad sense in that it denotes not only a reduction of an aberration, but also more generally a modification in such a way that the aberration can be reduced in a more straightforward manner using other correction means. In the case of a wavefront deformation, for example, it is sometimes better to transform a rotationally asymmetric wavefront deformation into a rotationally symmetric wavefront deformation that is equally "strong" or even "stronger", but can be reduced more easily by other means such as a displacement of certain lenses along the optical axis.

There are different ways in which the fluid flow may be variably illuminated with heating light. In the simplest case the heating light illumination system produces a single fixed irradiance distribution on the fluid flow, but only during certain times that are determined by a control unit. The temperature distribution in the fluid flow will then be determined primarily by the fixed irradiance distribution on the one hand, the velocity and direction of the fluid flow and the times during which the irradiance distribution is produced on the fluid flow.

A wider variety of temperature distributions may be produced in the fluid flow if the heating light illumination system is configured to produce, either intermittently or continuously, a plurality of different spatially varying irradiance distributions on the fluid flow. If the irradiance distributions are continuously varied, the heating light illumination system may be configured to produce an irradiance distribution on the fluid flow which synchronously moves with the fluid flow. In other words, a certain volume element of the fluid flow is exposed over a certain time to the same irradiance while this volume element moves along the flow direction. Then even temperature distributions with large gradients can be produced on the fluid flow.

Since also for fluids it takes some time until a desired temperature distribution is obtained by the partial absorption of the heating light, the heating light illumination system should be arranged in such a manner that, if seen along a flow direction of the fluid flow, the heating light impinges on the fluid flow at a position which is in front of the position where the projection light impinges on the fluid flow. Then it is ensured that a volume element in the fluid flow is exposed for a sufficiently long time to the heating light before this volume element enters the space through which the projection light passes.

If the fluid is a gas, for example air, hydrogen, carbon dioxide or sulfur hexafluoride, the fluid flow may freely propagate through a volume, through which projection light passes, without a need for any guide structures. However, in that case it is often difficult to ensure a sufficient laminarity of the gas flow. Furthermore, such a free gas flow tends to expand, which results in undesired density variations which will affect also the refractive index distribution.

For that reason it will generally be expedient, and if the fluid is a liquid even mandatory, to have a wavefront correction device that comprises a fluid channel that is configured to guide the fluid flow along a flow direction. The channel is defined by a channel wall, wherein at least a first portion of the channel wall is transparent for the projection light, and wherein at least a second portion of the channel wall, which preferably will, but does not necessarily have to be distinct from the first portion, is transparent for the heating light. Furthermore, the fluid channel is arranged in a beam path of the projection light such that a) the projection light passes through the first portion of the channel wall and b) the heating light passes through the second portion of the channel wall and the fluid flow.

The transparency of the first portion of the channel wall for the projection light on the one hand and of the second portion of the channel wall for the heating light should be at least 80%, and preferably above 95%. Preferably the Reynolds number which is associated with the fluid flows in the channel is below 3000, and more preferably below 2000, and still more preferably below 1200. This results in a laminar or at least quasi-laminar fluid flow in the channel.

In principle the channel may be open at the top so that the fluid flow gets in contact with a surrounding gas. Usually, however, it will be advantageous to use a channel formed by a conduit, i.e. a channel that is closed in all directions which are perpendicular to the flow direction, because this reduces any aberrations that may result from the contact between the fluid flow and the surrounding gas.

In principle the flow direction may be arranged at any angle with respect to the beam path of the projection light. Usually, however, it will be expedient if the flow direction is at least substantially perpendicular to the beam path of the projection light.

If the apparatus is of the scanner type, it comprises a mask stage which is configured to displace a mask containing a pattern along a scan direction, a projection light illumination system that is configured to illuminate the mask with the projection light, a substrate stage which is configured to move a substrate supporting the light sensitive layer, and a projection objective which is configured to image a region of the pattern, which is illuminated by the projection light while the mask is displaced along the scan direction, on the light sensitive surface.

In some embodiments the flow direction is parallel to the scan direction. Then the fluid flow and the mask may either have a different velocity, or the velocity is equal which results in a synchronous movement of the fluid flow and the mask. Such a synchronous movement is particularly advantageous if a transmission filter is displaced along the scan direction together with the mask, as it will be explained in more detail below.

In other embodiments the flow direction is perpendicular to the scan direction and to a beam path of the projection light. Such an arrangement has some advantages with respect to the space that is usually available to accommodate additional components such as the fluid supply unit and the heating light illumination system.

In apparatus of the scanner type the irradiance distribution produced by the heating light illumination system on the fluid flow may be variable while the mask is displaced along the scan direction. Then it is possible to correct wavefront deformations associated with the pattern contained in the mask and changing during a single scan cycle.

In some embodiments the heating light illumination system comprises a heating light source and a spatial light modulator that is arranged in a heating light path between the heating light source and the fluid flow. The spatial light modulator is used to produce different spatially varying irradiance distributions on the fluid flow.

To this end the spatial light modulator may comprise an array of mirrors or an LCD panel, for example. In other embodiments the spatial light modulator comprises a transmission filter having a transmission distribution that is non-uniform, and a transport device that is configured to displace the transmission filter while the mask is displaced along the scan direction. With such a moving transmission filter it is possible to produce a heating light irradiance distribution on the fluid flow which is synchronized with the scan movement of the mask. This is particularly useful if also the movement of the fluid flow is synchronized with the movement of the mask.

A perfect synchronization is achieved if the transmission filter is formed by a portion of the mask or by a filter element that is supported by a mask carrier supporting the mask. Then the mask transport device is formed by the mask stage itself, and thus an additional transport device and control means for synchronizing the movements of the transmission filter and the mask can be completely dispensed with.

In other embodiments the heating light illumination system comprises a plurality of individual heating light sources that are configured to be controlled independently from each other. The control of a spatial modulator comprising a plurality of pixel elements such as micro-mirrors or liquid crystals is thus replaced by the control of the individual heating light sources.

If the individual heating light sources are arranged in a two-dimensional array, very complex and almost arbitrary temperature distributions can be produced inside the fluid flow. This particularly applies if the array is arranged at least substantially parallel to the fluid flow, and in particular between the mask and the fluid flow.

The fluid supply unit may comprise a temperature controller that is configured to set the temperature of the fluid flow in such a way that the fluid flow, after being heated by the heating light in the projection light, does not affect the heat balance of the correction device. In other words, the net amount of heat produced by the partial absorption of the heating light and the projection light is compensated by a cooling of the fluid which is emitted by the fluid supply unit. This increases the effectiveness on the one hand and reduces problems that are associated with a correction device that produces a varying amount of heat during the operation of the apparatus.

The correction device may be used most advantageously if the fluid flow is synchronized with the movement of the mask during a scan cycle. As mentioned further above, then even very quickly changing field dependent wavefront deformations can be corrected. This requires that the fluid flow is arranged very closely to the mask. More specifically, it is preferred to arrange the mask and the fluid flow at a distance which is smaller than 50 mm and preferably smaller than 25 mm. However, in principle the fluid flow may also be arranged in or in close vicinity to a pupil plane of the projection objective.

In many cases it will be expedient if the projection light has a central projection light wavelength and the heating light has a central heating light wavelength, wherein the fluid has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength. Preferably the coefficients differ by a factor of more than 2, and more preferably by more than 10. Then the heating light is more strongly absorbed by the fluid than the projection light, for which the transmission should be as large as possible.

It is furthermore an object of the present invention to provide a method of correcting an aberration in a microlithographic projection exposure apparatus. The method shall be capable of correcting a wide variety of different and quickly changing rotationally asymmetric wavefront deformations.

This object is achieved, in accordance with the present invention, by a method comprising the following steps:

a) producing a fluid flow through which projection light, which finally impinges on a light sensitive surface, passes;

b) variably illuminating the fluid flow with heating light, which does not impinge on the light sensitive surface.

The above remarks relating to the apparatus in accordance with present invention apply here, mutatis mutandis, as well.

A plurality of different spatially varying irradiance distributions may be produced successively, in particular intermittently or continuously, on the fluid flow.

The fluid flow may be heated up by the heating light before the projection light impinges on it.

The fluid flow may extend along a flow direction which is at least substantially perpendicular to a beam path of the projection light.

If a mask containing a pattern is displaced along a scan direction while a region of the pattern is imaged on a light sensitive surface, the plurality of different spatially varying irradiance distributions may be produced while the mask is displaced along the scan direction.

In some embodiments a transmission filter, which has a transmission distribution that is non-uniform, is displaced while the mask is displaced along the scan direction. In particular, the transmission filter may be displaced by a mask stage that displaces the mask along the scan direction.

In other embodiments a plurality of individual heating light sources direct heating light beams on the fluid flow. These heating light sources may be controlled such that a moving irradiance distribution is produced on the fluid flow. In particular, the moving irradiance distribution may have a direction and a velocity which coincide with a direction and a velocity, respectively, of the fluid flow. Thus a synchronized movement of the irradiance distribution and the fluid flow is achieved.

DEFINITIONS

The term "light" denotes any electromagnetic radiation, in particular visible light, UV, DUV and VUV light.

The term "light ray" is used herein to denote light whose path of propagation can be described by a line.

The term "light beam" is used herein to denote a plurality of light rays. A light beam usually has an irradiance profile across its diameter that may vary along the propagation path.

The term "surface" is used herein to denote any planar or curved surface in the three-dimensional space. The surface may be part of a body or may be completely separated therefrom.

The term "optically conjugate" is used herein to denote the imaging relationship between two points or two surfaces. Imaging relationship means that a light bundle emerging from a point converges at the optically conjugate point.

The term "field plane" is used herein to denote a plane that is optically conjugate to the mask plane.

The term "pupil plane" is used herein to denote a plane in which all light rays, which converge or diverge under the same angle in a field plane, pass through the same point. As usual in the art, the term "pupil plane" is also used if it is in fact not a plane in the mathematical sense, but is slightly curved so that, in a strict sense, it should be referred to as pupil surface.

The term "transmission filter" is used herein to denote any device which reduces the intensity of light passing through it. Light which is not transmitted may be absorbed, reflected or scattered.

The term "wavefront correction" is used to denote any modification of a wavefront such that the wavefront is either a better approximation to an ideal undisturbed wavefront, or such that the wavefront can be more easily modified by other means such that it finally approximates better an ideal undisturbed wavefront.

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 is a perspective simplified view of a projection exposure apparatus in accordance with the present invention;

FIG. 2 is a meridional section through the apparatus shown in FIG. 1;

FIG. 3 is a view similar to FIG. 1, but at a later instance during a single scan cycle;

FIGS. 4 and 5 are top views on a wavefront correction device contained in the apparatus shown in FIGS. 1 to 3, but with different grey filters, at two different instances during a single can cycle;

FIGS. 6 and 7 are top views similar to FIGS. 4 and 5, but with still another set of grey filters;

FIG. 8 is a schematic view on a wavefront correction device according to an alternative embodiment in which the direction of a liquid flow is perpendicular to the scan direction;

FIG. 9 is a simplified top view on the wavefront correction device shown in FIG. 8;

FIGS. 10a to 10c are highly schematic representations of the liquid flow and the grey filter illustrating the implications of the orthogonal arrangement of the liquid flow and the scan direction;

FIGS. 11 and 12 are schematic perspective views of a wavefront correction device according to a further embodiment in which a plurality of individual light sources produce a variable irradiance distribution on the liquid flow;

FIG. 13 is a bottom view on a heating light source unit contained in the wavefront correction device shown in FIGS. 11 and 12;

FIG. 14 is a cross-section along line XIV-XIV through the heating light source unit shown in FIG. 13;

FIG. 15	is a schematic top view on the wavefront correction device shown in FIGS. 1 to 3 showing important components of a liquid circuit;
FIG. 16	is a schematic perspective view on a correction device according to another embodiment in which the temperature of fluid flows is set by mixing hot and cold fluids;
FIG. 17	is a cross-section along line S-S through the correction device shown in FIG. 16;
FIGS. 18a and 18b	are schematic cross-sections, for two operating states, through a mixing valve that mixes hot and cold water;
FIG. 19	is a meridional section through a projection exposure apparatus similar to FIG. 2, but with a correction device that is arranged in an intermediate image plane of the projection objective;
FIG. 20	is a flow diagram illustrating important method steps of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

I. First Embodiment

1. General Design of Projection Exposure Apparatus

The general design of a first embodiment of a projection exposure apparatus in accordance with the present invention will now be described with reference to FIGS. 1 and 2, which are a perspective view of and a meridional section through the apparatus, respectively. Both illustrations are highly schematic and not to scale.

The projection exposure apparatus, which is denoted in its entirety by 10, comprises an illumination system 12 which produces a beam of projection light PL having a center wavelength of about 193, nm. The projection light beam illuminates a field 14 on a mask 16 containing a pattern 18 of minute structures. In this embodiment the illuminated field 14 has the shape of a rectangle. However, other shapes of the illuminated field 14, for example ring segments, and other wavelengths of the projection light PL are contemplated as well. The mask 16 is mounted on a mask carrier 17 which is supported by a mask stage comprising guide rails 19a, 19b.

A projection objective 20 containing a plurality of lenses L1 to L4 and having an optical axis OA images the portion of the pattern 18 within the illuminated field 14 onto a light sensitive layer 22, for example a photoresist, which is supported by a substrate 24. The substrate 24, which may be formed by a silicon wafer, is arranged on a wafer stage 25 (shown only in FIG. 2) such that a top surface of the light sensitive layer 22 is precisely located in an image plane IP of the projection objective 20. The mask 16 is positioned by means of the mask stage in an object plane OP of the projection objective 20. Since the latter has a magnification β with $|\beta|<1$, a minified image 18' of the illuminated portion of the pattern 18 is projected onto the light sensitive layer 22.

During the projection, the mask 16 and the substrate 24 move parallel to a scan direction which coincides with the Y direction, as this is indicated in FIG. 1 by arrows A1 and A2. The illuminated field 14 then scans over the mask 16 so that structured areas larger than the illuminated field 14 can be continuously projected. Such a type of projection exposure apparatus is often referred to as "step-and-scan tool" or simply a "scanner". The ratio between the velocities of the substrate 24 and the mask 16 is equal to the magnification β of the projection objective 20. If the projection objective 20 inverts the image ($\beta<0$), the mask 16 and the substrate 24 move in opposite directions.

In the embodiment shown, the illuminated field 14 is centered with respect to an optical axis OA of the projection objective 20. This is usually the case in dioptric projection objectives, i.e. objectives containing only refractive optical elements, but no mirrors. Examples for this type of projection objectives can be found in WO 2003/075096 A2. In other embodiments, the illuminated field 14 is not centered with respect to the optical axis OA. An off-axis object and image field may be necessary with certain types of catadioptric projection objectives 20, i.e. objectives that contain refractive as well as reflective optical elements. Examples for catadioptric projection objectives having off-axis object and image fields are described in US 6,665,126 B2 and WO 2005/069055 A2. In fact, the present invention can be advantageously used with any type of projection objective.

2. Wavefront Correction Device

The apparatus 10 comprises a wavefront correction device 26 for correcting, or more generally for modifying, aberrations. The causes for aberrations may be constant or time dependent. Constant causes include design deficiencies, impurities or other faults in lens materials or anti-reflection coatings, and mounting tolerances. Time dependent causes include variable ambient conditions such as air pressure and temperature, certain ageing phenomena such as material compaction caused by the high energy projection light PL, and deformations and refractive index changes induced by temperature changes due to the absorption of projection light PL within lens materials.

Aberrations are often quantitatively described by comparing real wavefronts to ideal wavefronts. The deviation of a real wavefront from the ideal wavefront is usually referred to as wavefront deformation and may be described by a complete set of normalized orthogonal functions such as Zernike polynomials. A deformation may be rotationally symmetrical or rotationally asymmetrical. Apart from that, wavefront deformations may be identical for all points in the image field, or may be different for some or each of these points. In the latter case, the aberration is referred to as being field-dependent.

Generally, the wavefront correction device 26 of the present invention is arranged and configured such that at least some of the aforementioned wavefront deformations can either be substantially reduced or at least modified in such a way that it can be reduced in a straightforward manner using other correction means. Such other correction means include, among others, manipulators that displace optical elements, the mask 16 or the substrate 24 along the optical axis OA or in a perpendicular direction.

If field-independent aberrations shall be corrected, the wavefront correction device should be arranged in or in close proximity to one of the pupil planes PP1, PP2 of the projection objective 20 as shown in FIG. 2. However, in the embodiment shown in FIG. 1, the wavefront correction device 26 is arranged and configured such that it is capable of correcting aberrations that are field-dependent. This means that the wavefront deformations are different for different field points in the image plane of the projection objective 20. To this end the wavefront correction device 26 is positioned in close proximity to the mask 16. Alternatively, the wavefront correction device 26 may be arranged in or in close proximity to an intermediate image plane IIP of the projection objective 20 which is optically conjugate to the object plane OP in which the mask 16 is arranged (see FIG. 2). In principle also an arrangement in close proximity to the image plane IP may be envisaged.

The correction device 26 shown in FIGS. 1 and 2 comprises a channel 28 having a rectangular cross-section. The channel 28 is defined by an upper wall, a lower wall and two side walls. The upper and lower walls are formed by a first and a second glass plate 30, 32, respectively, which extend in parallel XY planes being perpendicular to the optical axis OA of the projection objective 20. The side walls of the channel 28 are formed by two elongated spacer bars 34, 36 extending along the scan direction Y.

The channel 28 is connected to a liquid supply unit 38 which is configured to output a liquid flow 40 that moves through the channel 28 in an at least substantially laminar fashion. The geometry of the channel 28 is adapted to the liquid so that the Reynolds number which is associated with the liquid flow 40 is below 1200. As it will be explained further below in more detail with reference to FIG. 15, the liquid supply unit 38 comprises a pump, a filter and a heat exchanger so as to ensure that the liquid has a predetermined homogeneous temperature and uniform velocity when it enters the channel 28 and forms the liquid flow 40.

The correction device 26 further comprises a heating light illumination system that is configured to variably illuminate the liquid flow 40 with heating light HL. To this end the heating light illumination system comprises a first and a second heating light source 42, 44 that produce the heating light HL and direct it on the liquid flow 40. The heating light illumination system further comprises a spatial light modulator formed by a first and a second grey filter 46, 48 that are mounted on both sides of the mask 16 on the mask carrier 17 in such a manner that the heating light HL produced by the first heating light source 42 passes through the first grey filter 46 before it impinges on the liquid flow 40. Similarly, the heating light HL produced by the second heating light source 44 passes through the second grey filter 48 before it impinges on the liquid flow 40.

As can best be seen in the meridional section of FIG. 2, the heating light HL is, as a result of the inclined arrangement of the first and second heating light sources 42, 44, able to pass through the grey filters 46, 48 without impinging on the pattern 18 contained in the mask 16, but is nevertheless capable of illuminating a portion of the liquid flow 40 over almost its entire width. The distance d between the liquid flow 40 and the mask 16 in this embodiment is about 20 mm.

In the following the function of the correction device 26 will be explained in more detail:

The liquid supply unit 38 is controlled such that the liquid flow 40 moves along the scan direction Y with the same velocity as the mask carrier 17 on which the mask 16 and the grey filters 46, 48 of the heating light illumination system are mounted. Thus the liquid flow 40 is fully synchronized with the movement of the mask 16 and the grey filters 46, 48. This implies that the transmission distribution of the grey filters 46, 48 defines an irradiance distribution on the liquid flow 40 which moves parallel to and with the same velocity as the liquid flow 40 – and thus also as the mask 16 - during a scan cycle. Reference is made to FIG. 3 which shows the apparatus 10 at an instance after the mask carrier 17 has been moved further along the scan direction Y during the same scan cycle.

If one considers a particular volume element in the liquid flow 40, this will therefore be illuminated by the heating light HL through the same portion of the grey filter 46 or 48 on its way through the channel 28. As it can be seen best in FIG. 1, the heating light HL heats up the volume element before the projection light PL passes through it. Thus there is sufficient time for increasing the temperature inside the volume element before it enters the space through which projection light PL passes. If the volume element enters this space, the changed refractive index being a result of the increased temperature modifies the phase of the projection light PL so that a wavefront deformation is corrected.

The liquid supplied by the liquid supply unit 38 and forming the liquid flow 40 should have an extremely low coefficient of absorption for the projection light PL, but may have a very significant coefficient of absorption for the heating light HL. Therefore the central wavelength of the heating light HL will generally be different from the central wavelength of the projection light PL, and the coefficient of absorption for central heating wavelength should be at least 2 times, preferably at least 10 times higher than the coefficient of absorption for the projection light PL.

In the embodiment shown the liquid supplied by the liquid supply unit 38 is purified water and the heating light sources 44, 46 produce heating light HL having a central wavelength between 2 μm and 3 μm, which is in the infrared spectral range, or between 11 cm and 13 cm, which is in the microwave spectral range. If the projection light PL has a central wavelength of about 193 nm, the coefficient of absorption is less than 0.05 cm^{-1} for the projection light PL and about 10^2 cm^{-1} for heating light having a central wavelength of 2 μm. The stronger the coefficient of absorption for the heating light HL is, the more heating light HL will be absorbed by the liquid flow 40, and consequently the less heat is produced by other elements that absorb heating light HL which has passed through the second glass plate 32.

Other liquids that may be used by the correction device 26 instead of water include Fomblin® (perfluorpolyether), decalin (decahydronaphthalene), cyclodecane and tetraethyl orthosilicate.

II. Other embodiments

1. Grey filters

In the embodiment shown in FIGS. 1 to 3 it has been assumed that the grey filters 46, 48 comprise a plurality of areas with different coefficients of transmission.

FIGS. 4 and 5 are top views on the correction device 26 in which other types of grey filters 46, 48 are used. These grey filters 46, 48 both have a reflective surface 50 for the heating light HL, but are provided with circular apertures 52. At certain scan positions of the mask carrier 17 the apertures 52 enter the area which is illuminated by the first and second heating light sources 42, 44 on the grey filters 46, 48. Then heating light HL passing through the apertures 52 illuminates spots on the liquid flow 40. Since the apertures 52, and thus also the spots illuminated on the liquid flow 40, move with the same velocity and direction as the liquid flow 40, portions of the liquid flow 40 associated with the spots are successively heated by the heating light HL. The position of the heated up portions of the liquid flow 40 are assumed to correspond, in the simplified embodiment shown in FIGS. 4 and 5, with circular transparent regions 54 on the mask 16. If these regions 54 move into the illuminated field 14, as it is shown in FIG. 5, the heated portions in the liquid flow 40 are still directly underneath the regions 54. Consequently, the projection light PL passing through the regions 54 will also pass through the heated portions of the liquid flow 40. In this manner a correction of wavefront deformations may be achieved that are associated with the regions 54 in the mask 16.

FIGS. 6 and 7 show, in illustrations similar to FIGS. 4 and 5, grey filters 46, 48 which are adapted to a different mask 16. Here the grey filters 46, 48 comprise, similar to the embodiment shown in FIGS. 1 to 3, areas with different coefficients of transmission. Here the transmission distributions of the first and second grey filters 46, 48 are different from each other, because also the pattern 18 on the mask 16 is not symmetrical with respect to the YZ plane.

2. Perpendicular flow direction

FIG. 8 is a perspective view of another embodiment of a wavefront correction device 26 which is not part of the presently claimed invention. In this embodiment the channel 28 extends along the X direction, i.e. perpendicular both to the direction of the projection light beam and to the scan direction Y indicated by arrow A1. Thus also the direction of the liquid flow 40 is perpendicular to the scan direction Y. For that reason the heating light illumination system comprises only one heating light source 42 and one grey filter 46 that are arranged, if seen along the direction of the liquid flow 40, in front of the mask 16. In this embodiment the grey filter is an opaque plate comprising a plurality of apertures 52.

As can best be seen in the schematic top view on the correction device 26 shown in FIG. 9, the orthogonal arrangement of the liquid flow 40 and the scan direction Y has significant implications for the design of the grey filter 46 if a certain heating light irradiance distribution shall be produced on the liquid flow 40. If this irradiance distribution shall move substantially synchronously with the liquid flow 40 along the flow direction, it has to be taken into account that a surface element of the grey filter 46 does not move parallel to a volume element of the liquid flow 40, but in an orthogonal direction.

This is illustrated in FIGS. 10a to 10c, which schematically show the grey filter 46 and the liquid flow 40 in three different relative positions. Here it is assumed that a cubic volume element 55 shall be illuminated by the heating light HL for a certain time period. To this end the grey filter 46 is provided with an aperture 52 having approximately the shape of an oblique line which is sized and oriented such that the volume element 55 is constantly illuminated by the heating light HL although the liquid flow 40 and the grey filter 46 move along orthogonal directions.

The same considerations apply, of course, if more complex irradiance distributions shall be produced on the liquid flow 40 such that they move synchronously and substantially stationary with the liquid flow 40 for a certain time period.

3. Multiple heating light sources

In the embodiments described above it has been assumed that the heating light illumination system comprises one or two heating light sources and some kind of spatial light modulator that produces, from a single heating light beam, variable irradiance distributions on the liquid flow. In the following an embodiment of a wavefront correction device 26 will be described with reference to FIGS. 11 to 14 in which the heating light illumination system comprises a plurality of individual heating light sources that can be controlled independently from each other so that variable irradiance distributions can be produced on the liquid flow 40.

FIGS. 11 and 12 are schematic perspective views of such a correction device 26 at two different instances during a single scan cycle. Similar to the embodiments shown in FIGS. 1 to 7, the direction of the liquid flow 40 is parallel to the scan direction Y, and also the velocity of the liquid flow 40 is equal to the velocity of the mask 16 during a scan cycle.

Between the mask 16 and the first and second glass plates 30, 32 defining the upper and lower walls of the channel 28, a heating light source 42 is arranged that comprises a plurality of individual heating light sources that can be controlled individually to produce individual heating light beams 58.

FIG. 13 is a bottom view of the heating light source 42 in which a plurality of positive lenses 60 can be seen that are associated with the individual heating light sources. The positive lenses 60, and thus also the individual heating light sources, are arranged in a two-dimensional regular array which extends in a plane which is parallel to the liquid flow 40.

FIG. 14 is a schematic cross-section along line XIV-XIV through the heating light source 42 shown in FIG. 13. There it can be seen that the positive lenses 60 are used to collimate the heating light which is emitted by the individual heating light sources denoted by 62. The individual heating light sources 62 may be formed by light emitting diodes (LED), for example. The individual heating light sources 62 are arranged on an electronic circuit board 64 which is connected to a control unit (not shown) which controls the heating light sources 62 individually.

Referring again to FIGS. 11 and 12, it can be seen that the heating light beams 58 emitted by the individual light sources 62 propagate, as collimated beams, through the upper glass plate 30, the liquid flow 40 and the lower glass plate 32. The irradiance distribution on the liquid flow 40 is determined by the intensity of the individual heating light beams 58 produced by the heating light sources 62. Since the latter can be controlled individually, it is possible to produce almost any arbitrary irradiance distribution on the liquid flow 40.

Furthermore, it is possible to produce an irradiance distribution that moves synchronously with the liquid flow 40. This is illustrated in FIGS. 11 and 12. It can be seen that the irradiance distribution, which is indicated by small spots 66 illuminated by the heating light beams 58 on the upper glass plate 30, changes while the liquid flow 40 moves synchronously with the mask 16 along the scan direction Y.

4. Heat balance

FIG. 15 is a top view on several components of the wavefront correction device 26 shown in FIGS. 1 to 3. For the sake of simplicity, the first and second heating light sources 42, 44 are not shown.

It can be seen that in addition to the liquid supply unit 38 a liquid collecting unit 70 is arranged at the opposite end of the channel 28. Liquid collected by the liquid collecting unit

70 if returned to the liquid supply unit 38 via a return channel 72. Before the liquid returned to the liquid supply unit 38 enters again the channel 28, it is processed in a processing unit 74 of the liquid supply unit 38. The processing unit 74 comprises a heat exchanger 76, a pump 78 and a filter 80. The temperature of the liquid is set, with the help of the heat exchanger 76, so that the liquid flow 40 does not affect the heat balance of the wavefront correction device 26 after the liquid flow 40 has been heated by the heating light HL and - although to a lesser extent - by the projection light PL. In other words, the heat produced primarily by absorption of the heating light HL is constantly removed from the liquid in the processing unit 74. This ensures that the temperature of the liquid does not increase continuously while the liquid circulates through the channel 28, the liquid collecting unit 70, the return channel 72 and the liquid supply unit 38. As a result, the liquid flow 40 has a constant temperature when it enters the region where it is illuminated by the heating light HL. This avoids thermal problems that are associated with a permanent heat source in the apparatus 10 and also improves the effectiveness of the correction device 26, because larger temperature gradients inside the liquid flow 40 can be achieved.

5. Other types of fluid heating devices

In the foregoing it has been assumed that the temperature distribution in the fluid flow 40 is modified by producing a variable irradiance distribution of heating light HL on the fluid flow 40. However, there are also other means to vary a variable temperature distribution in a medium that moves synchronously with the mask 16.

FIG. 16 is a simplified and not to scale perspective view on another correction device 26' that is preferably arranged in the projection objective 20 at the same axial position (i.e. close to the object plane OP of the projection objective 20) as the correction device 26 shown in FIG. 2. In this embodiment the correction device 26' comprises a gas supply unit 156 and a suction unit 157. Components that are contained in these units will be described in more detail further below with reference to FIG. 17. The units 156, 157 are spaced apart by a substantially empty space 155 through which projection light PL propagates during operation of the apparatus 10.

The gas supply unit 156 comprises two rows of gas outlet apertures 144 (only visible in the cross section of FIG. 17) that have, in the embodiment shown, a circular cross section. The rows of gas outlet apertures 144 are arranged along the X direction in a staggered manner and in two parallel planes that are separated by a horizontal glass plate 158 extending through the otherwise empty space 155. Two additional horizontal glass plates 160, 162, which are arranged parallel to the horizontal glass plate 158, commonly define, together with two vertical glass plates 164, 166 and the units 156, 157, an upper cavity 168 and a lower cavity 170. The height of the cavities 168, 170 may be in the range of a few millimeters or as small as about 1 mm. During operation of the correction device 26', gas flows 172 propagate through the cavities 168, 170 along the Y direction. The gas flows 172 are emitted by the gas outlet apertures 144 arranged at one end of each cavity 168, 170.

The suction unit 157 comprises a similar arrangement of gas inlet apertures 145 from which the gas flows 172 are sucked off after having traversed the cavities 168, 170. The gas inlet apertures 145 are arranged opposite the gas outlet apertures 144 in a one to one correspondence. They are therefore arranged in the same staggered manner as the gas outlet apertures 144.

FIG. 17 is a cross sectional view through the correction device 26' shown in FIG. 16 along a sectional plane which is indicated in FIG. 16 by S-S. The gas supply unit 156 contains a plurality of channels 173 each terminating at one end in one of the gas outlet apertures 144. At the opposite end each channel 173 bifurcates into two channel sections, one section terminating at a cold gas container 174 containing a cold gas and the other section terminating at a hot gas container 176 containing a hot gas. In the embodiment shown nitrogen (N_2) is used as gas, but other gases such as helium (He) may also be used. Generally, the gas should have a negligible coefficient of absorption for the projection light PL.

A hot gas control valve 178 is provided in the channel section between the hot gas container 176 and the bifurcation point that is associated to a particular gas outlet aperture 144. The hot gas control valve 178, which is controlled by a common control unit (not shown), is configured to feed, per time unit, variable numbers of hot gas molecules taken from the hot gas container 176 into the channel section that finally leads to the gas outlet aperture 144.

A cold gas control valve 179 is provided in the channel section between the cold gas container 174 and the bifurcation point that is associated to a particular gas outlet aperture 144. The cold gas control valve, which is also controlled by the common control unit (not shown), is configured to feed, per time unit, variable numbers of cold gas atoms or molecules taken from the cold gas container 174 into the channel section that finally leads to the gas outlet aperture 144. In this manner the number density of hot and cold gas atoms or molecules in the gas flows 172 emerging from the gas outlet apertures 144 can be adjusted finely and individually for each gas outlet aperture 144 with the help of the purge gas control valves 179. In particular it is possible to keep the number density of the gas flows 172 constant while varying their temperature and thus their refractive index. In principle it is also possible to additionally vary the number density of the gas flows 172, because the number density influences the refractive index, too. However, since the number density influences the velocity of the gas molecules, it becomes difficult to maintain a constant velocity of the gas flow.

The suction unit 157 of the second filter unit 154 comprises channels 182 connecting the gas inlet apertures 145 to a suction pump 186. The suction pump 186 produces a negative pressure so that the individual gas flows emerging from the gas outlet apertures 144 are sucked off by the suction unit 180 and form a plurality of parallel laminar gas flows 172 extending through the cavities 168, 170. Since the temperature can be controlled individually for each gas flow 172, it is possible to produce a non-homogenous temperature distribution in the cavities 168, 170.

The pressure in the hot and cold gas containers 174, 176 and the negative pressure produced by the suction pump 186 are controlled such that the fluid flows 172 move through the cavities 168, 170 with a direction and velocities that are equal to the direction and the velocity of the mask 16 that is arranged in immediate proximity to the correction device 26'. In this manner a very similar effect is achieved as in the case of the embodiments described previously.

It is also possible to use a liquid instead of a gas in the correction device 26'. Furthermore, it is possible to use only a single mixing valve instead of the hot gas control valve 178 and the cold gas control valve 179.

FIGS. 18a and 18b illustrate the principle of such a single mixing valve for an embodiment in which cold water 274' and hot water 276' are mixed to produce a fluid flow 272 having a variable temperature. The mixing valve designated by 280 comprises a slide 282 that is guided by a guide rail 284. With the help of a drive 286 the slide 282 can be displaced between a first position, in which the slide 282 completely blocks the cold water 274' (see FIG. 18b), and a second position, in which the slide 282 completely blocks the hot water 276'. In intermediate positions, for example the position shown in FIG. 18a, the slide 282 combines variable fractions of cold water 274' and hot water 276' to form the fluid flow 272 having the desired temperature.

The mixing valve 280 has the advantage that it can be switched very quickly, because the mass of the slide 282 is small. It is thus possible to produce a fluid flow 272 having a temperature that may change very rapidly. With a quick drive 286, for example a piezoelectric stack, zhe response time may be as small as a few milliseconds.

FIG. 19 illustrates another embodiment of a correction device 26" in a representation similar to FIG. 2. In this embodiment the correction device 26" is not arranged in immediate vicinity to the mask 16, but in the intermediate image plane IIP. The fluid flow 40 is thus arranged in a position that is optically conjugate to the object plane OP in which the mask 16 is arranged.

In this embodiment the correction device 26" has a similar construction as the correction device 26' as shown in FIGS. 16 and 17. However, there is only one cavity through which the gas flows 172 propagate. The temperature of the individual fluid flows 172 is not varied by mixing a hot and a cold gas, but by directing IR light produced by an IR diode 184 on an individual gas flow 172. By controlling the IR diodes 184 associated to the various gas flows 172 individually, it is thus possible to produce a variable and moving temperature distribution in the intermediate image plane IIP.

Since the magnification $|\beta'|$ of the real image formed in the intermediate image plane IP is generally distinct from 1, the velocity and possibly also the direction of the fluid flows 172 have to be adapted to the magnification β. In the embodiment shown it is assumed that $|\beta|>1$, but $\beta<0$, so that the fluid flows 172 propagate with a larger velocity as the mask 16, but in the opposite direction (+Y) as compared to the mask 16 (-Y).

III. Important aspects of the method

FIG. 20 is a flow diagram that illustrates important steps of the method in accordance with the present invention.

In a first step S1 a mask is displaced along a scan direction.

In a second step S2 a fluid flow having a temperature distribution is produced. The fluid flow moves parallel to and with the same velocity as the mask.

In a third step S3 the temperature distribution of the fluid flow is varied.

This makes it possible to correct aberrations that are caused by the moving mask and/or the moving substrate.

IV. Other important aspects of the invention

In the following other important aspects of the invention are summarized as sentences. The applicant reserves the right to direct claims on the subjects of these sentences in this application or in a divisional application.

1. A microlithographic projection exposure apparatus, comprising a correction device (26) that comprises

    a) a fluid supply unit (38) that is configured to produce a fluid flow (40) through which projection light (PL), which finally impinges on a light sensitive surface (22), passes, and

    b) a heating light illumination system (42, 44, 46, 48) that is configured to variably illuminate the fluid flow (40) with heating light (HL), which does not impinge on the light sensitive surface (22).

2. The apparatus of sentence 1, wherein the heating light illumination system (42, 44, 46, 48) is capable of producing a plurality of different spatially varying irradiance distributions on the fluid flow (40).

3. The apparatus of sentence 2, wherein the heating light illumination system (42, 44, 46, 48) is configured to produce an irradiance distribution on the fluid flow (40) which synchronously moves with the fluid flow (40).

4. The apparatus of any of the preceding sentences, wherein the heating light illumination system (42, 44, 46, 48) is arranged in such a manner that, if seen along a flow direction (Y) of the fluid flow (40), the heating light impinges on the fluid flow (40) at a position which is in front of the position where the projection light (PL) impinges on the fluid flow (40).

5. The apparatus of any of the preceding sentences, wherein the projection light (PL) has a central projection light wavelength, and wherein the heating light (HL) has a central heating light wavelength, and wherein a fluid forming the fluid flow (40) has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength.

6. The apparatus of any of the preceding sentences, wherein the correction device (26) comprises a fluid channel (28) that

    - is configured to guide the fluid flow (40) along a flow direction (Y),

- is defined by a channel wall, wherein a least a first portion (30) of the channel wall is transparent for the projection light (PL), and wherein at least a second portion (30) of the channel wall, which is not necessarily distinct from the first portion, is transparent for the heating light (HL), and
- is arranged in a beam path of the projection light (PL) such that the projection light (PL) passes through the first portion (30) of the channel wall and the fluid flow (40) and that the heating light (HL) passes through the second portion (30) of the channel wall and the fluid flow (40).

7. The apparatus of any of the preceding sentences, wherein the apparatus further comprises:

   c) a mask stage (19a, 19b) which is configured to displace a mask (16) containing a pattern (18) along a scan direction (Y),

   d) a projection light illumination system (12) that is configured to illuminate the mask (16) with the projection light (PL),

   e) a substrate stage (25) that is configured to move a substrate (24) supporting the light sensitive layer (22);

   f) a projection objective (20) which is configured to image a region (14) of the pattern (18), which is illuminated by the projection light (PL) while the mask (16) is displaced along the scan direction, on the light sensitive surface (22).

8. The apparatus of sentence 7, wherein the flow direction is parallel to the scan direction (Y).

9. The apparatus of sentence 7, wherein the flow direction is perpendicular to the scan direction and to a beam path of the projection light (PL).

10. The apparatus of any of sentences 7 to 9 and comprising the features of sentence 2, wherein the irradiance distribution produced by the heating light illumination system (42, 44, 46, 48) on the fluid flow (40) is variable while the mask (16) is displaced along the scan direction (Y).

11. The apparatus of any of sentences 7 to 10, wherein the correction device (26) is arranged between the mask (16) and a projection objective (20) that is configured to image mask (16) on the light sensitive surface (22).

12. The apparatus of any of the preceding sentences, wherein the heating light illumination system comprises a heating light source (42, 44) and a spatial light modulator (46, 48) that is arranged in a heating light path between the heating light source (42, 44) and the fluid flow (40).

13. The apparatus of sentence 12 and comprising the features of sentence 7, wherein the spatial light modulator comprises

    - a transmission filter (46, 48) having a transmission distribution that is non-uniform, and a
    - transport device (19a, 19b) that is configured to displace the transmission filter while the mask (16) is displaced along the scan direction (Y).

14. The apparatus of sentence 13, wherein the transmission filter is formed by a portion of the mask or by a filter element (46, 48) that is supported by a mask carrier (17) supporting the mask (16), and wherein the mask transport device is formed by the mask stage (19a, 19b).

15. The apparatus of any of the preceding sentences, wherein the heating light illumination system comprises a plurality of individual heating light sources (62) that are configured to be controlled independently from each other.

16. The apparatus of sentence 15, wherein the individual light sources (62) are arranged in a two-dimensional array.

17. The apparatus of any of the preceding sentences, wherein the projection light (PL) has a central projection light wavelength and the heating light has a central heating light wavelength, and wherein the fluid has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength.

18. A method of correcting a aberration in a microlithographic projection exposure apparatus (10), the method comprising the following steps:

    a) producing a fluid flow (40) through which projection light (PL), which finally impinges on a light sensitive surface (22), passes;

    b) variably illuminating the fluid flow (40) with heating light (HL), which does not impinge on the light sensitive surface (22).

19. The method of sentence 18, wherein a plurality of different spatially varying irradiance distributions are successively produced on the fluid flow (40).

20. The method of sentence 18 or 19, wherein the fluid flow (40) is heated up by the heating light (HL) before the projection light (PL) impinges on it.

21. The method of any of sentences 17 to 20, wherein the projection light (PL) has a central projection light wavelength, and wherein the heating light (HL) has a central heating light wavelength, and wherein the fluid has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength.

22. The method of any of sentences 18 to 21, wherein the fluid flow (40) extends along a flow direction which is at least substantially perpendicular to a beam path of the projection light (PL).

23. The method of sentence 22, wherein a mask (16) containing a pattern (18) is displaced along a scan direction (Y) while a region of the pattern (18) is imaged on the light sensitive surface (22).

24. The method of sentence 23, wherein the flow direction is parallel to the scan direction (Y).

25. The method of sentence 23, wherein the flow direction is perpendicular to the scan direction (Y).

26. The method of sentence 19 and comprising the features of any of sentences 23 to 25, wherein the plurality of different spatially varying irradiance distributions are produced while the mask (16) is displaced along the scan direction (Y).

27. The method of any of sentences 23 to 26, wherein a transmission filter (46, 48), which has a transmission distribution that is non-uniform, is displaced while the mask (16) is displaced along the scan direction (Y).

28. The method of sentence 27, wherein the transmission filter is displaced by a mask stage (19a, 19b) that displaces the mask (16) along the scan direction (Y).

29. The method of any of sentences 18 to 28, wherein a plurality of individual heating light sources (62) direct heating light beams (58) on the fluid flow (40).

30. The method of sentence 29, wherein the plurality of heating light sources (62) is controlled such that a moving irradiance distribution is produced on the fluid flow (40).

31. The method of sentence 31, wherein the moving irradiance distribution has a direction and a velocity which coincide with a direction and velocity, respectively, of the fluid flow (40).

32. The method of any of sentences 18 to 31, wherein a temperature of the fluid is controlled in such a way that the fluid flow (40), after being heated by the heating light (HL) and the projection light (PL), does not affect the heat balance of the correction device (26).

CLAIMS

1. A microlithographic projection exposure apparatus, comprising

   a) a primary illumination system (12) configured to illuminate a mask (16), which contains a pattern, (18) with projection light,

   b) a mask stage (19a, 19b) configured to displace the mask (16) along a scan direction (Y),

   c) a projection objective (20) configured to image a field (14), which is illuminated on the mask (16) with the projection light (PL)) while the mask is displaced along the scan direction, on a light sensitive surface (22),

   d) a substrate stage (25) that is configured to move a substrate (24) supporting the light sensitive layer (22) synchronously with the mask (16);

   e) a correction device (26; 26'; 26") that comprises

      - a fluid supply unit (38) configured to produce a fluid flow (40) through which the projection light (PL) passes, wherein the fluid flow (40) moves, during a scan exposure of the light sensitive surface (22), parallel to and with the same velocity as the mask (16), and

      - a fluid heating device (42, 44, 46, 48) configured to produce a variable temperature distribution in the fluid flow (40) so that also the temperature distribution moves at least substantially parallel to and with the same velocity as the mask (16).

2. The apparatus of claim 1, wherein the fluid heating device comprises a heating light illumination system (42, 44, 46, 48) that is configured to variably illuminate the fluid flow (40) with heating light (HL) that does not impinge on the light sensitive surface (22).

3. The apparatus of claim 2, wherein the heating light illumination system (42, 44, 46, 48) is capable of producing a plurality of different spatially varying irradiance distributions on the fluid flow (40).

4. The apparatus of claim 2 or 3, wherein the heating light illumination system (42, 44, 46, 48) is configured to produce an irradiance distribution on the fluid flow (40) which moves parallel to and with the same velocity as the fluid flow (40).

5. The apparatus of any of claims 2 to 4, wherein the heating light illumination system (42, 44, 46, 48) is arranged in such a manner that, if seen along a flow direction (Y) of the fluid flow (40), the heating light impinges on the fluid flow (40) at a position which is upstream of the position where the projection light (PL) impinges on the fluid flow (40).

6. The apparatus of any claims 2 to 5, wherein the projection light (PL) has a central projection light wavelength and the heating light (HL) has a central heating light wavelength, and wherein a fluid forming the fluid flow (40) has a coefficient of absorption for the central heating light wavelength that is greater than a coefficient of absorption for the central projection light wavelength.

7. The apparatus of any of claims 2 to 6, wherein the correction device (26) comprises a fluid channel (28) that

   - is configured to guide the fluid flow (40) along a flow direction (Y),
   - is defined by a channel wall, wherein a least a first portion (30) of the channel wall is transparent for the projection light (PL), and wherein at least a second portion (30) of the channel wall, which is not necessarily distinct from the first portion, is transparent for the heating light (HL), and
   - is arranged in a beam path of the projection light (PL) such that the projection light (PL) passes through the first portion (30) of the channel wall and the fluid flow (40) and that the heating light (HL) passes through the second portion (30) of the channel wall and the fluid flow (40).

8. The apparatus of any of the preceding claims, wherein the correction device (26') comprises a plurality of fluid outlet apertures (144), and wherein the fluid heating device comprises a plurality of temperature control units (178, 179; 280) each being configured to change the temperature of the fluid emerging from the fluid outlet apertures (144) in response to a control signal.

9. The apparatus of claim 8, wherein each temperature control unit is connected to a first reservoir (174) filled with fluid having a first temperature and to a second reservoir (176) filled with fluid having a second temperature which is higher than

the first temperature, and wherein each temperature control unit comprises a fluid mixing device (178, 179; 280) configured to mix fluid from the first reservoir and fluid from the second reservoir to obtain a mixed fluid that has a temperature that is between the first temperature and the second temperature.

10. The apparatus of any of the preceding claims, wherein the temperature distribution in the fluid flow (40) is variable while the mask (16) is displaced along the scan direction (Y).

11. The apparatus of any of the preceding claims, wherein the correction device (26) is arranged between the mask (16) and a first optical element (L1) of the projection objective (20) on its object side.

12. A method of correcting a aberration in a microlithographic projection exposure apparatus (10), the method comprising the following steps:

    a) displacing a mask (16) containing a pattern (18) along a scan direction (Y) while a field on the mask (16) is imaged on a light sensitive surface (22);

    b) simultaneously with step a), producing a fluid flow (40) that has a temperature distribution and moves parallel to and with the same velocity as the mask (16) so that projection light (PL), which finally impinges on a light sensitive surface (22), passes through the fluid flow;

    c) varying the temperature distribution of the fluid flow (40) while the mask is displaced.

13. The method of claim 12, wherein the fluid flow (40) is illuminated with heating light (HL) that does not impinge on the light sensitive surface (22).

14. The method of claim 13, wherein the fluid flow (40) is heated up by the heating light (HL) before the projection light (PL) impinges on it.

15. The method of claims 13 or 14, wherein a transmission filter (46, 48), which has a transmission distribution that is non-uniform, is displaced while the mask (16) is displaced along the scan direction (Y), and wherein the heating light (HL) impinges on the transmission filter before it impinges on the fluid flow (40).

16. The method of claim 15, wherein the transmission filter is displaced by a mask stage (19a, 19b) that displaces the mask (16) along the scan direction (Y).

17. The method of any of claims 13 to 16, wherein a plurality of individual heating light sources (62) direct heating light beams (58) on the fluid flow (40), and wherein the plurality of heating light sources (62) is controlled such that a moving irradiance distribution is produced on the fluid flow (40).

18. The method of claim 17, wherein the moving irradiance distribution has a direction and a velocity which coincide with a direction and velocity, respectively, of the mask (40).

19. The method of any of claims 12 to 18, wherein the temperature distribution of the fluid is controlled in such a way that the fluid flow (40) does not affect the heat balance of the correction device (26).

20. A microlithographic projection exposure apparatus, comprising

a) a primary illumination system (12) configured to illuminate a mask (16) containing a pattern (18) with projection light,

b) a mask stage (19a, 19b) configured to displace the mask (16) along a scan direction (Y),

c) a projection objective (20) configured to image a field (14), which is illuminated on the mask (16) with the projection light (PL)) while the mask is displaced along the scan direction, on a light sensitive surface (22),

d) a substrate stage (25) that is configured to move a substrate (24) supporting the light sensitive layer (22) synchronously with the mask (16);

e) a correction device (26) that is arranged in an intermediate image plane (IIP) of the projection objective (20) and comprises

   – a fluid supply unit (38) that is configured to produce a fluid flow (40) through which the projection light (PL) passes, wherein the fluid flow (40) moves, during a scan exposure of the light sensitive surface (22), parallel to and with the same velocity as a real image of the mask (16) that is formed in the intermediate image plane (IIP), and

   – a fluid heating device (42, 44, 46, 48) that is configured to produce a variable temperature distribution in the fluid flow (40) so that also the temperature distribution moves at least substantially parallel to and with the same velocity as the real image of the mask (16).

21. A method of correcting a aberration in a microlithographic projection exposure apparatus (10), the method comprising the following steps:

    a) displacing a mask (16) containing a pattern (18) along a scan direction (Y) while a field on the mask (16) is imaged by a projection objective (20) on a light sensitive surface (22);

    b) simultaneously with step a), producing a fluid flow (40) in an intermediate image plane (IIP) of the projection objective (20), wherein the fluid flow (40) has a temperature distribution and moves parallel to and with the same velocity as a real image of the mask (16) that is formed in the intermediate image plane (IIP) so that projection light (PL), which finally impinges on a light sensitive surface (22), passes through the fluid flow;

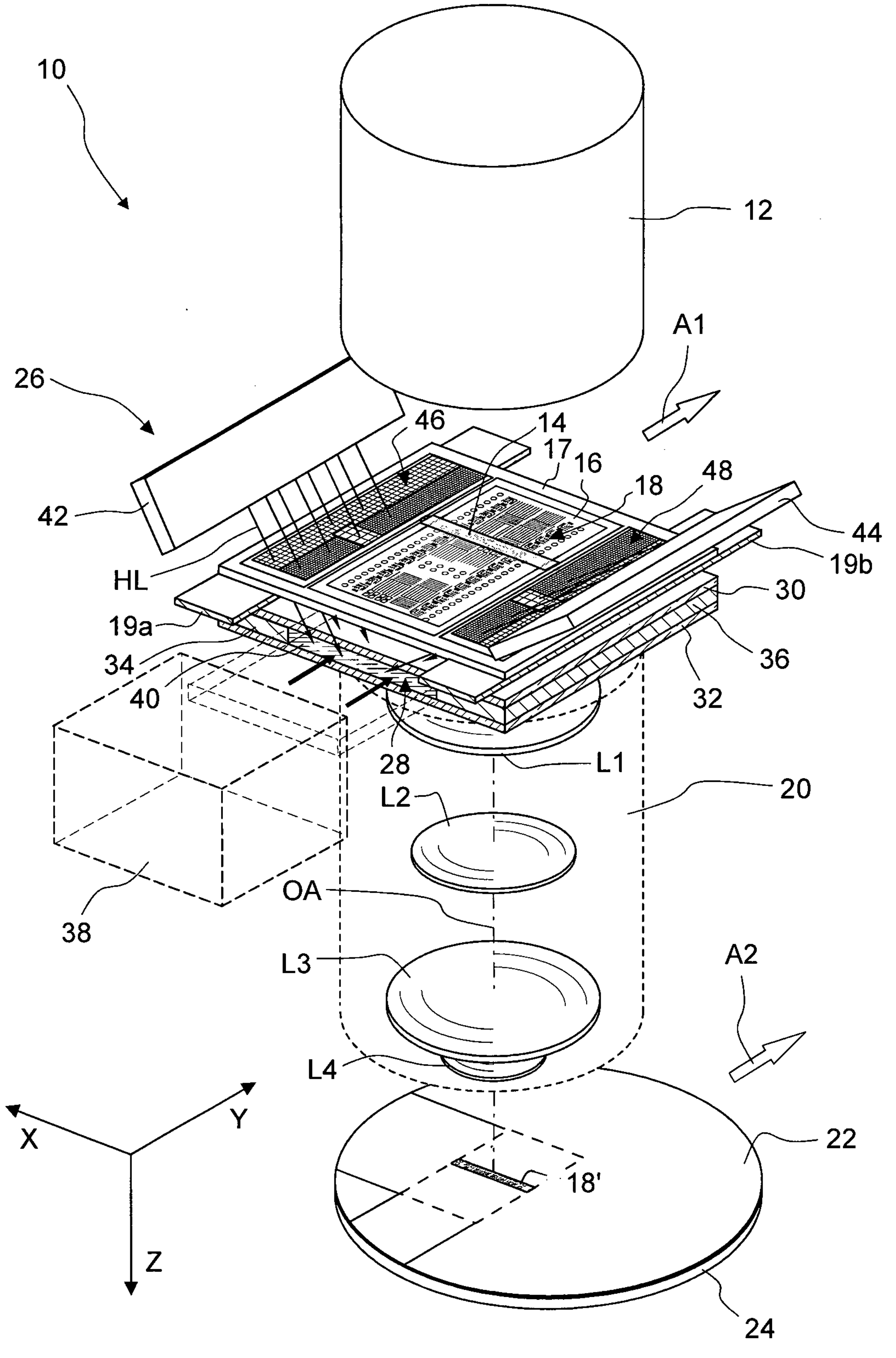
    c) varying the temperature distribution of the fluid flow (40) while the mask is displaced.

22. A method of correcting a aberration in a microlithographic projection exposure apparatus (10), the method comprising the following steps:

    a) displacing a mask (16) along a scan direction (Y);

    b) producing a fluid flow (40) having a temperature distribution and moving parallel to and with the same velocity as the mask;

    c) varying the temperature distribution of the fluid flow.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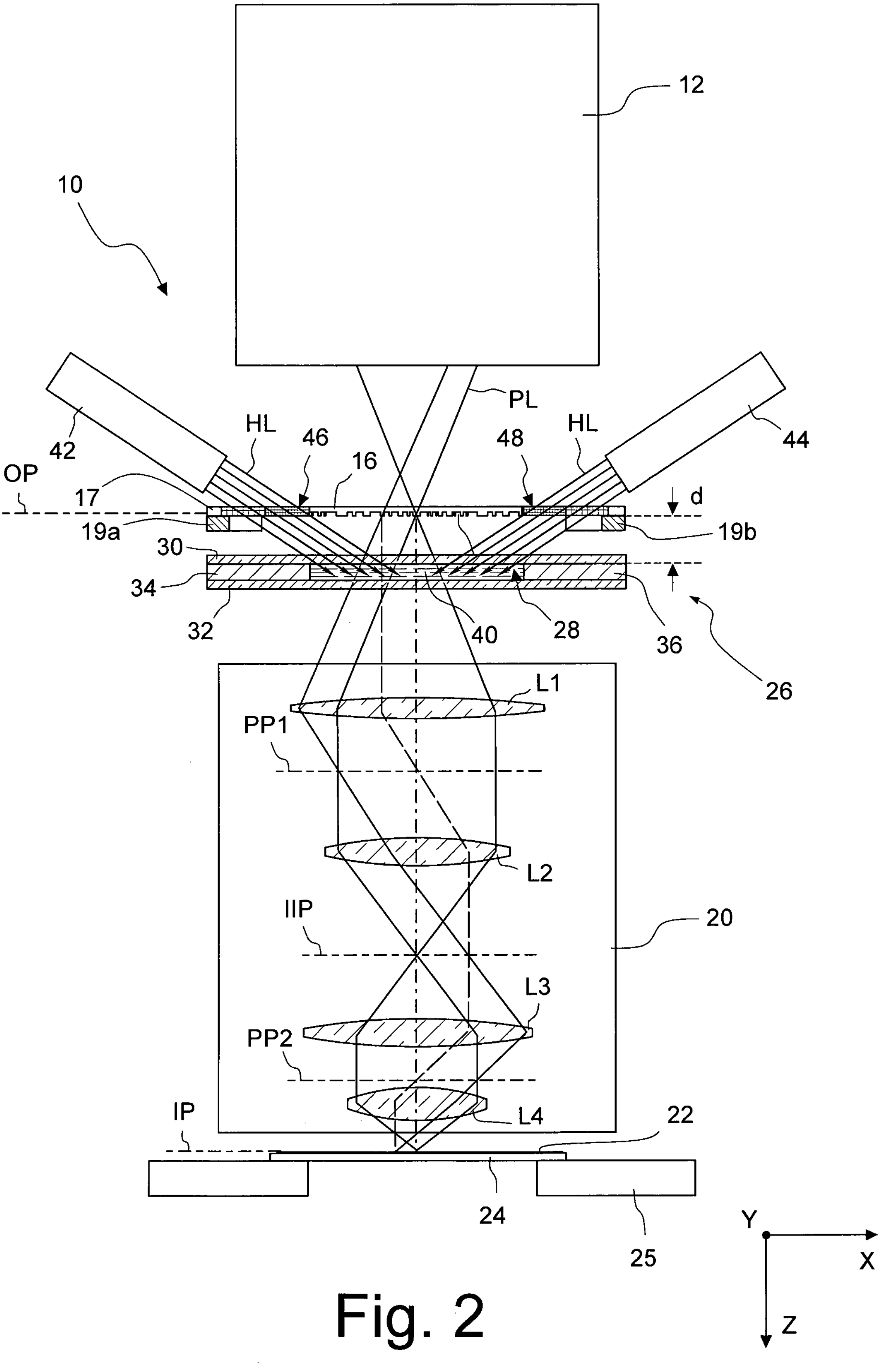
12
A1
26
46
14
17
16
18
48
44
42
HL
19b
30
19a
34
36
40
32
28
L1
L2
20
OA
38
A2
L3
L4
X
Y
22
18'
Z
24

Fig. 1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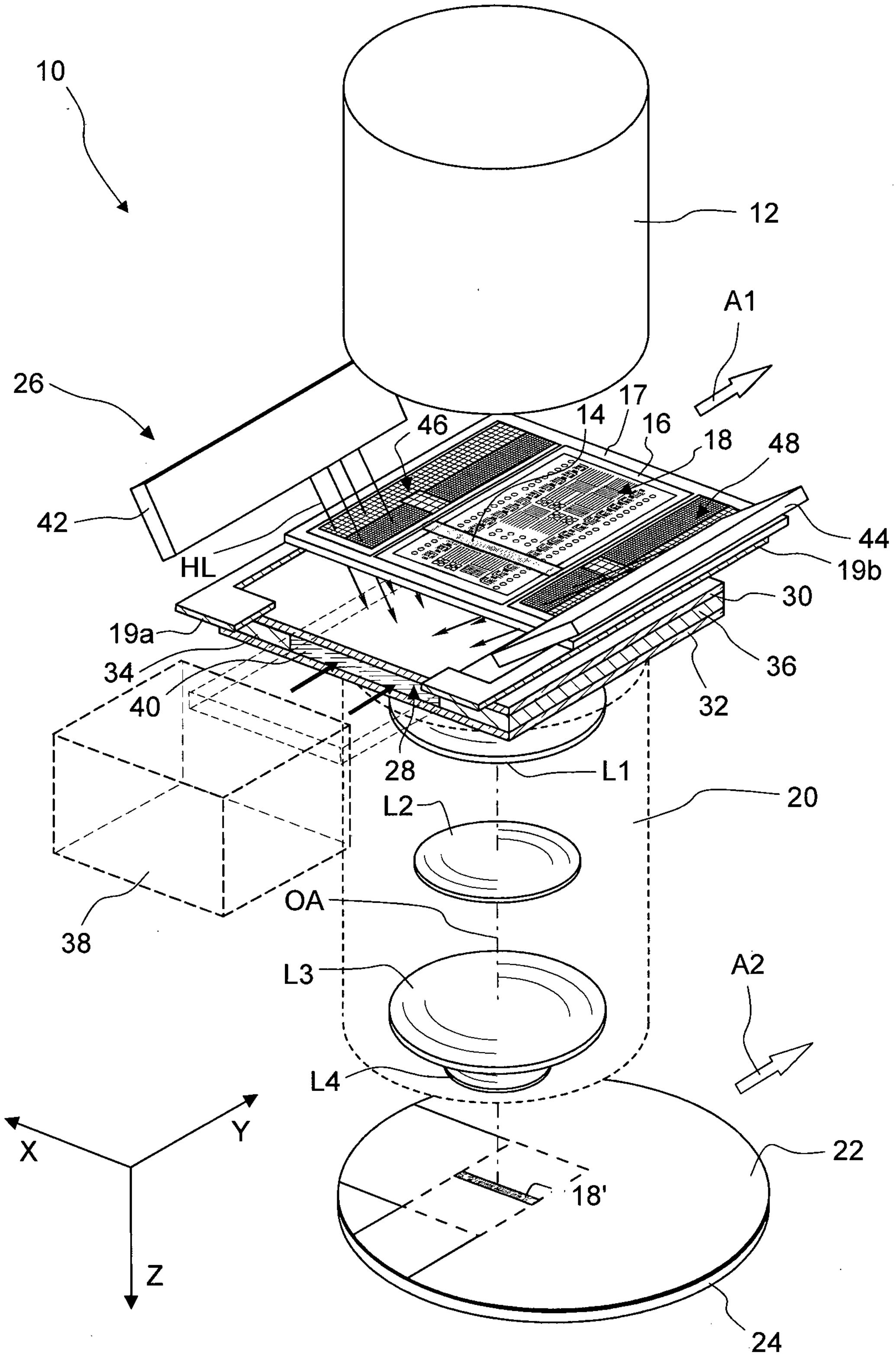
10
PL
42
HL
46
16
48
HL
44
OP
17
d
19a
19b
30
34
40
28
36
32
26
L1
PP1
L2
IIP
20
L3
PP2
L4
IP
22
24
25
Y
X
Z

Fig. 2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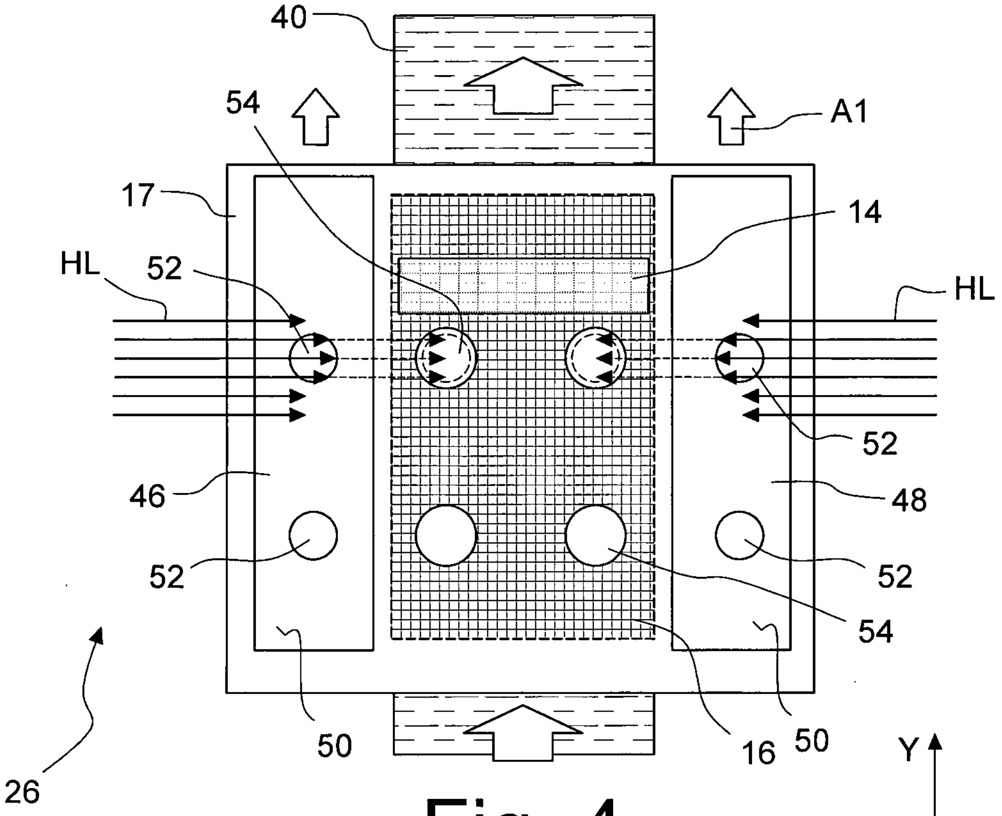
12
A1
26
46
14
17
16
18
48
42
HL
44
19b
30
19a
34
36
40
32
28
L1
L2
20
OA
38
L3
A2
L4
X
Y
22
18'
Z
24

Fig. 3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A1
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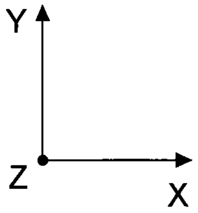
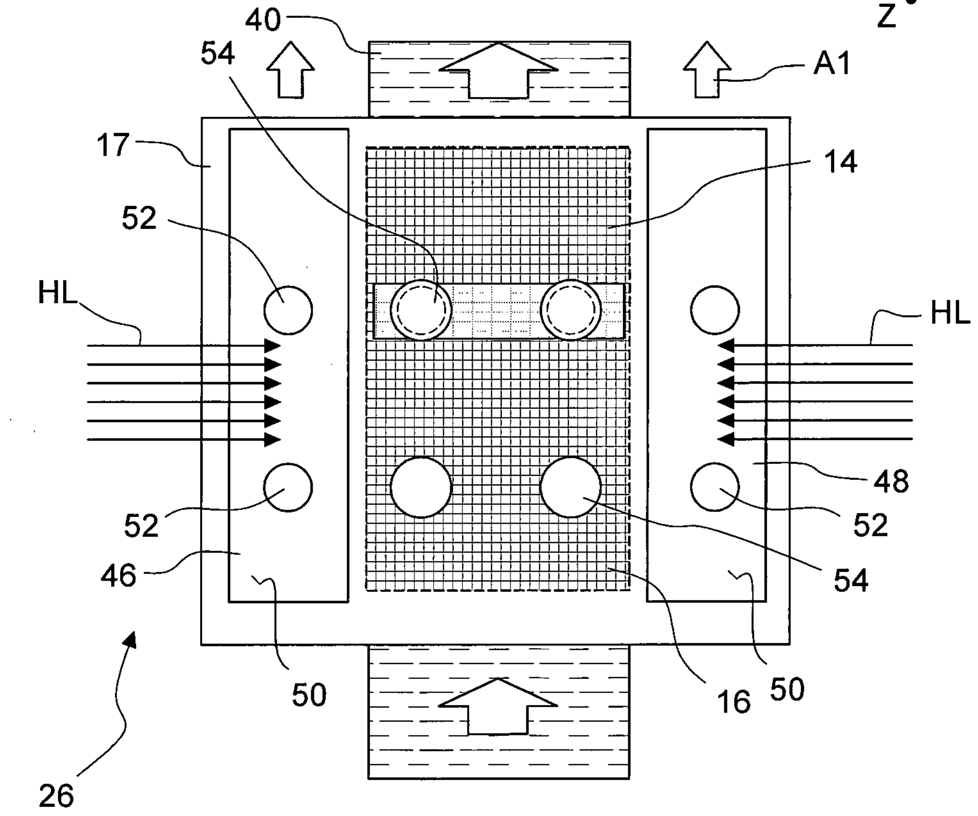
14
HL
52
HL
52
46
48
52
52
54
50
16
50
26

Fig. 4


Y
Z
X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A1
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14
52
HL
HL
48
52
52
46
54
50
16
50
26

Fig. 5

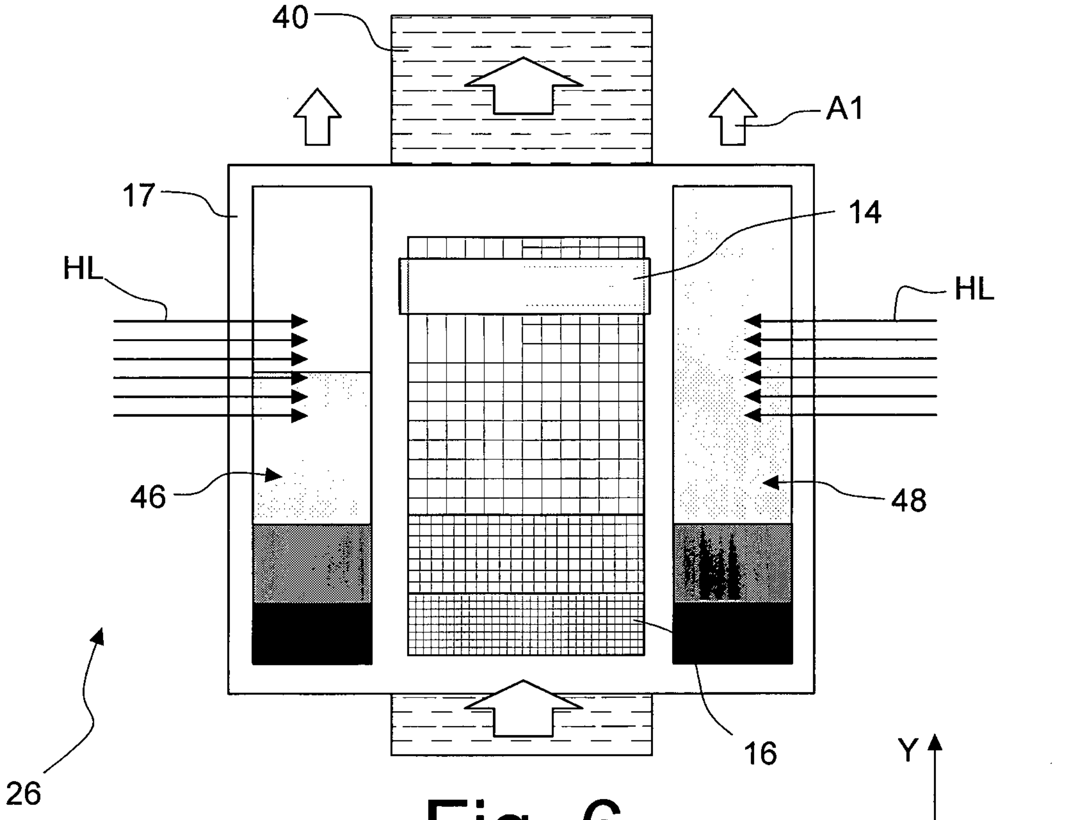


Fig. 6

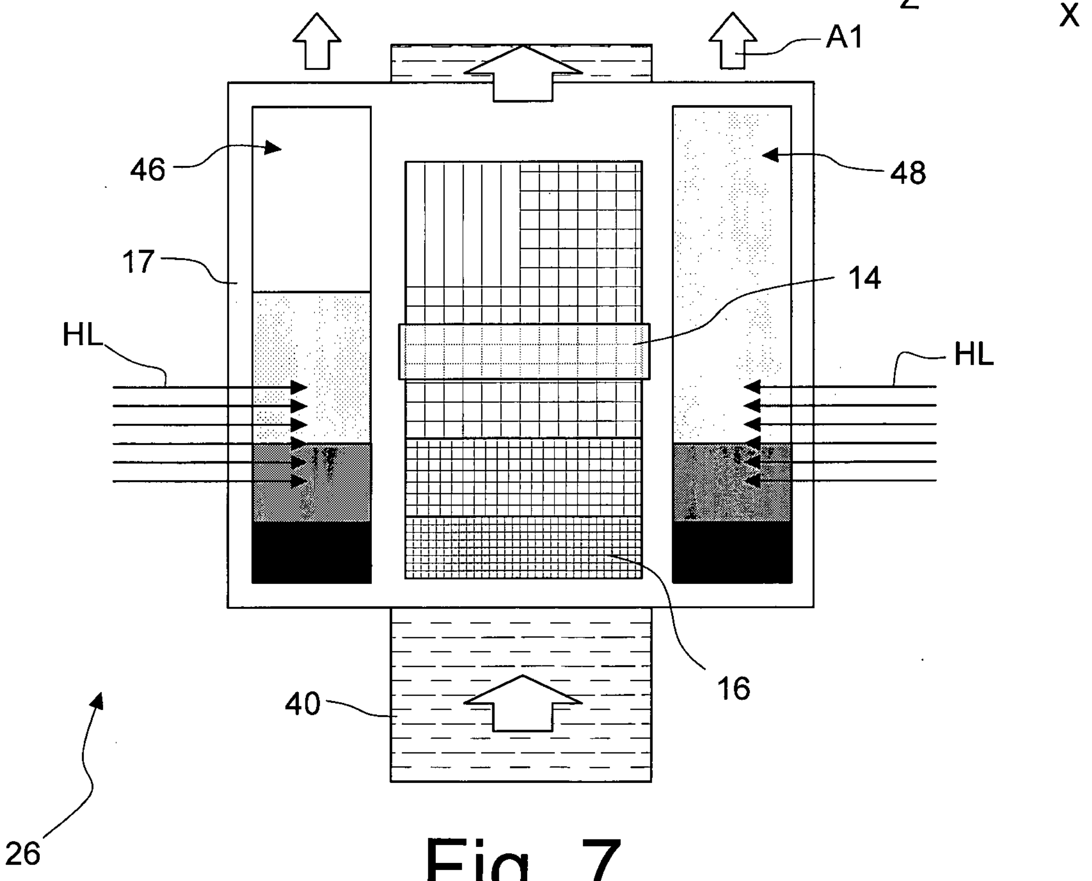


Fig. 7

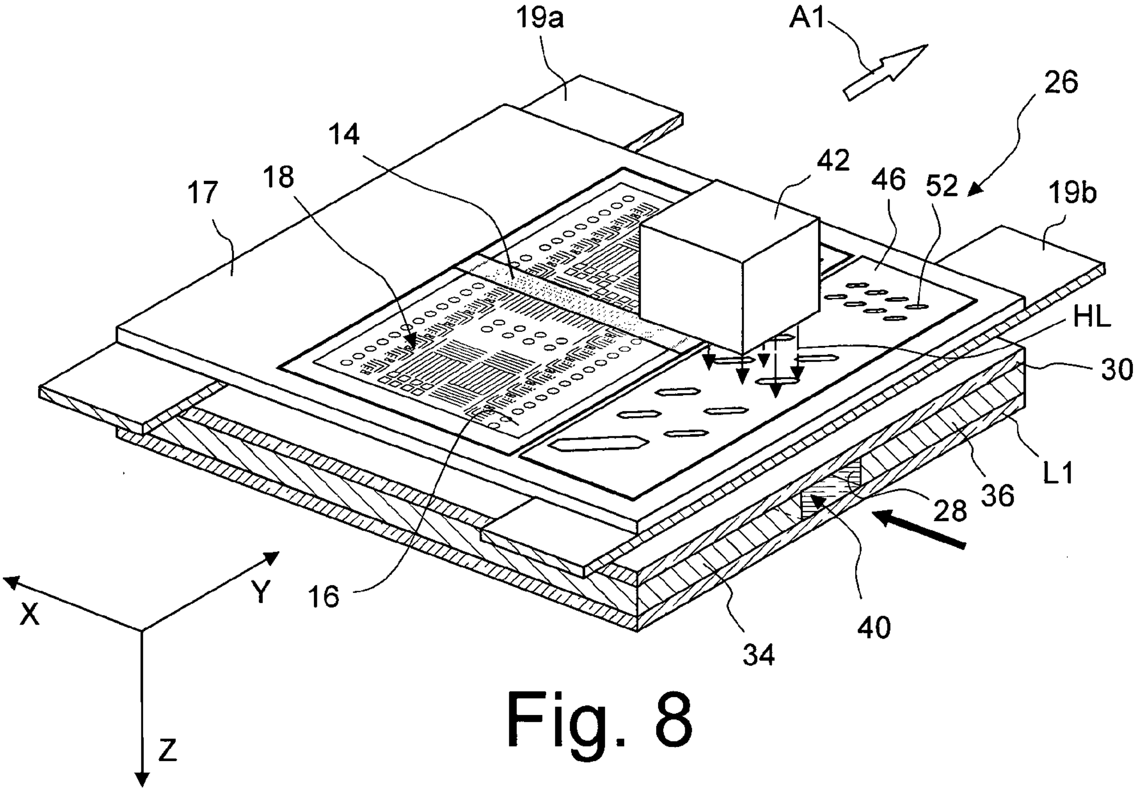
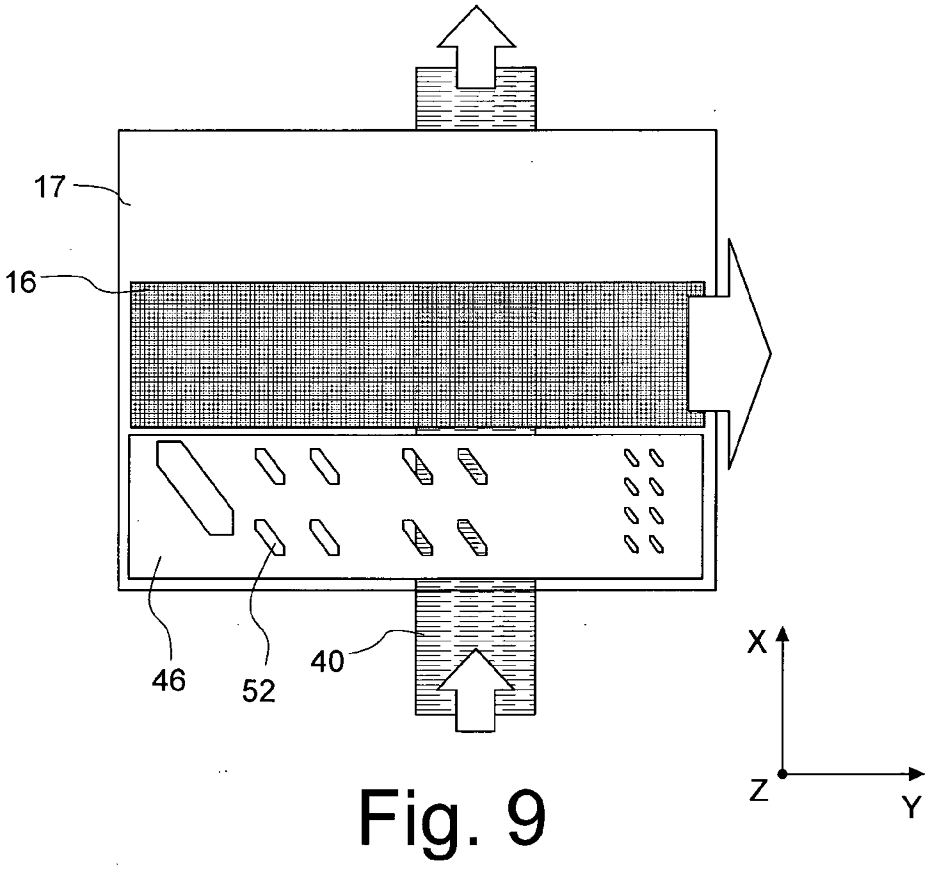

19a
A1
26
14
42
46
52
19b
17
18
HL
30
L1
36
28
40
34
16
X
Y
Z

Fig. 8


17
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52
40
X
Z
Y

Fig. 9

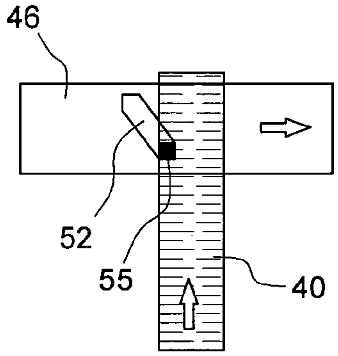


Fig. 10a

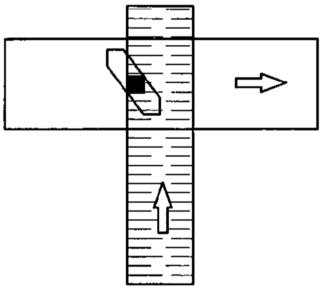


Fig. 10b

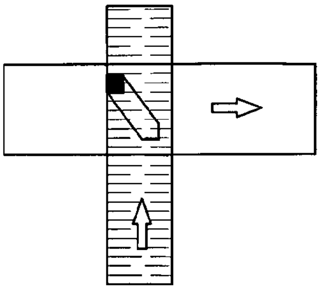


Fig. 10c

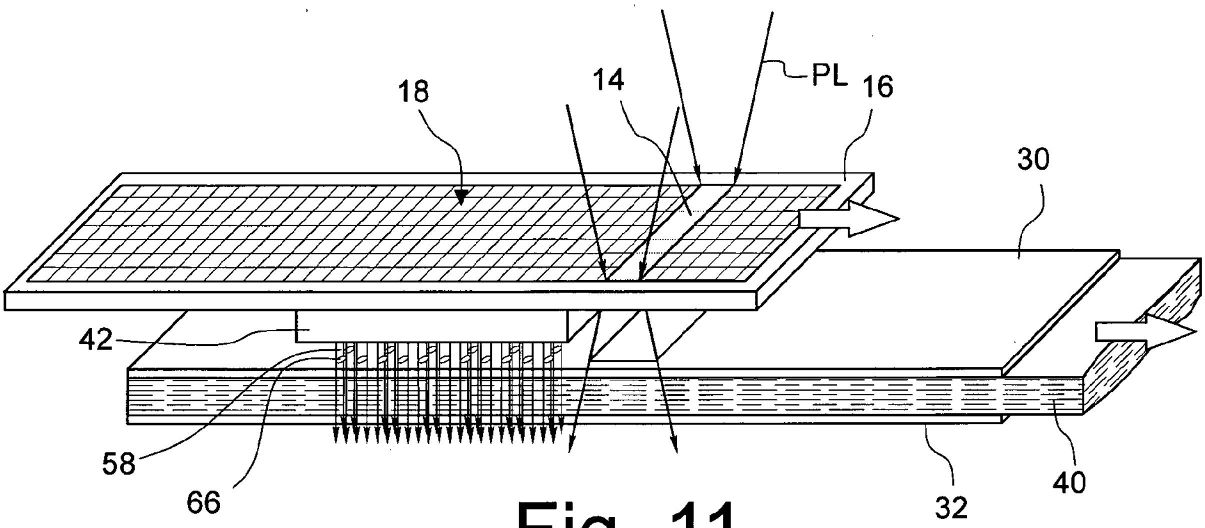


Fig. 11

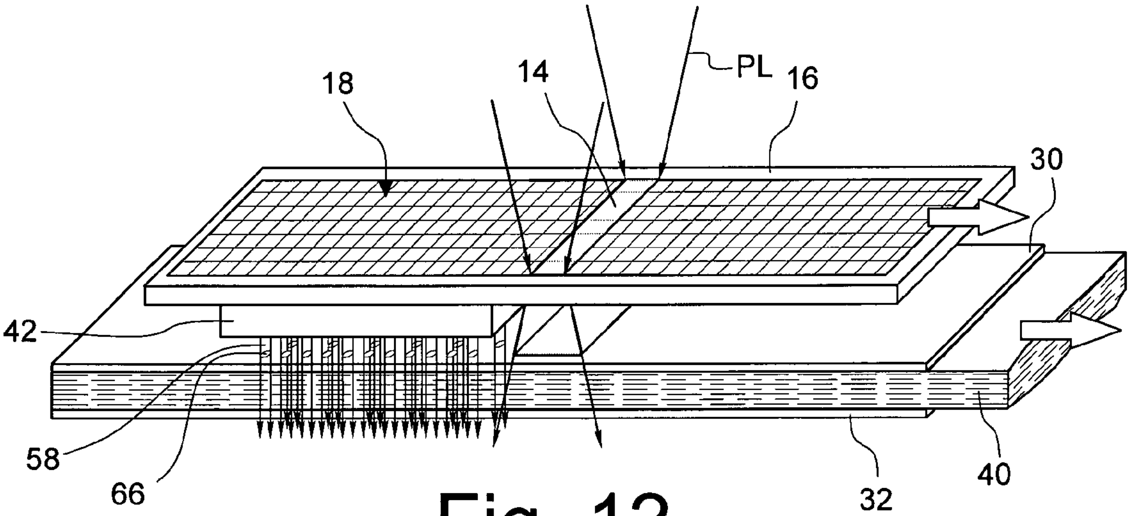


Fig. 12

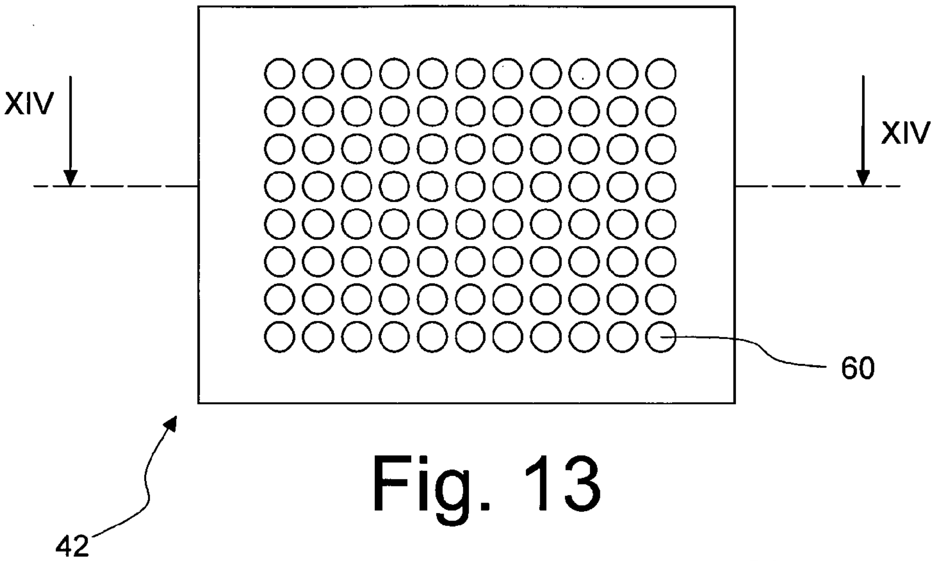


Fig. 13

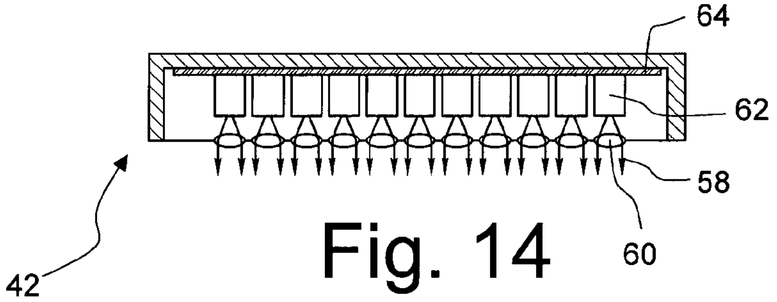


Fig. 14

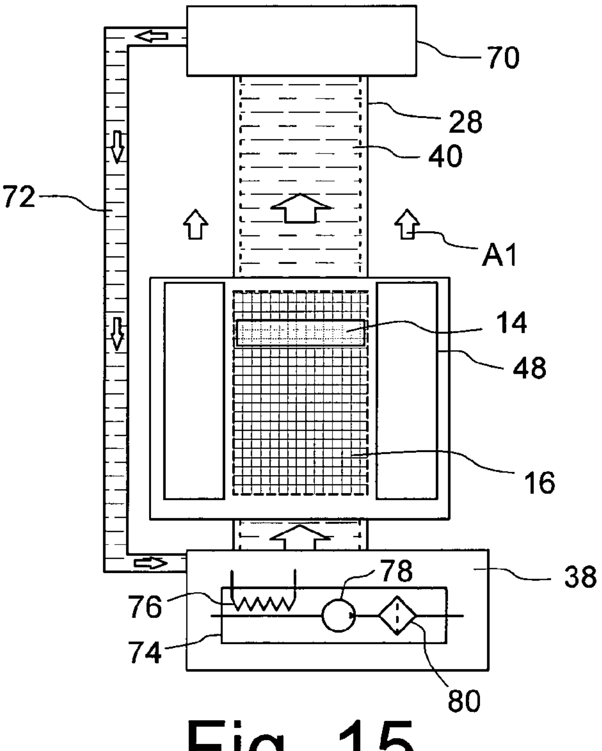


Fig. 15

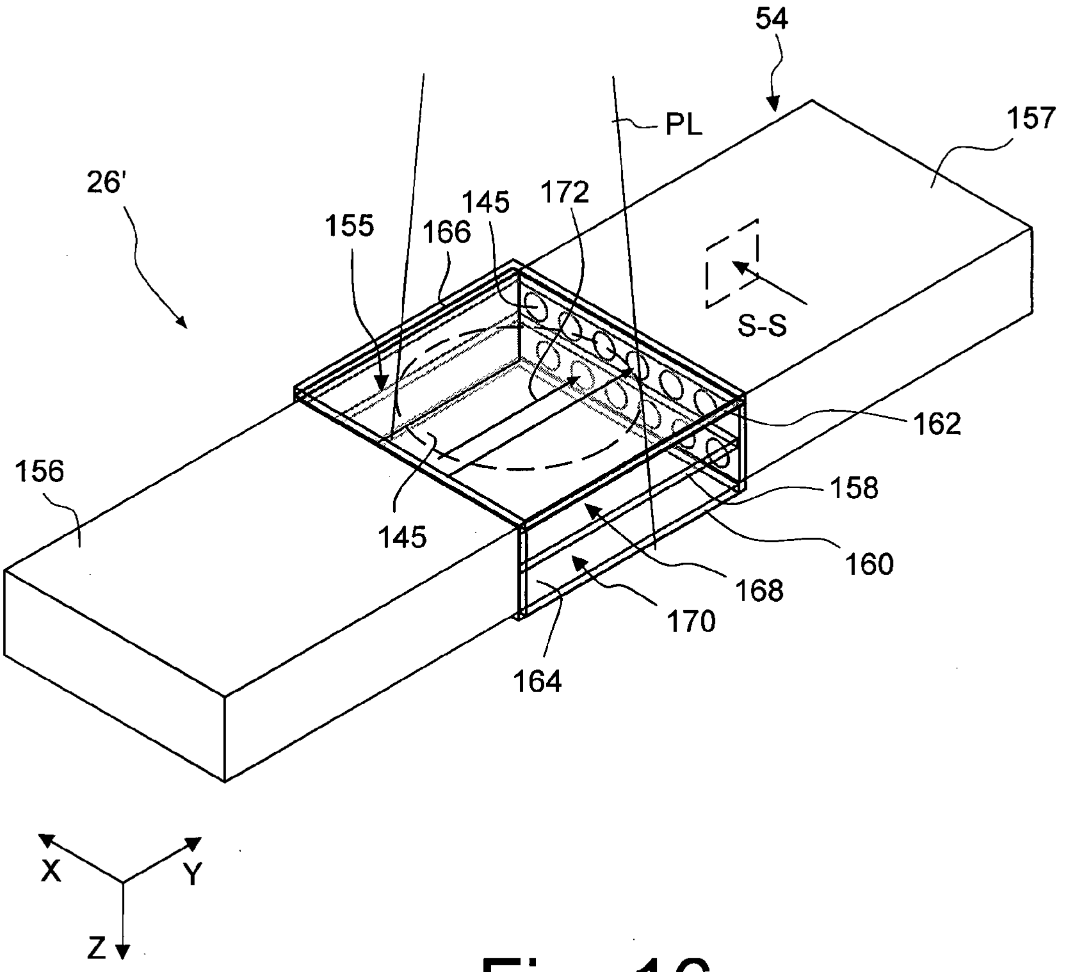

54
PL
157
26'
155
166
145
172
S-S
162
156
158
145
160
168
170
164
X
Y
Z

Fig. 16

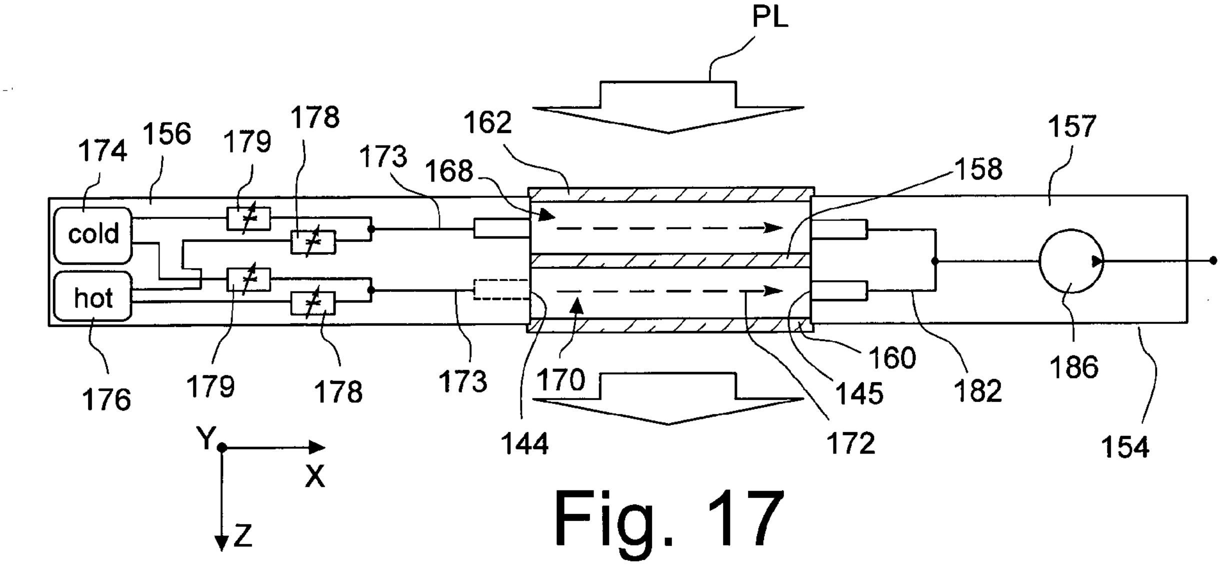

PL
178
162
157
174
156
179
173
168
158
cold
hot
176
179
178
173
170
144
172
145
160
182
186
154
Y
X
Z

Fig. 17

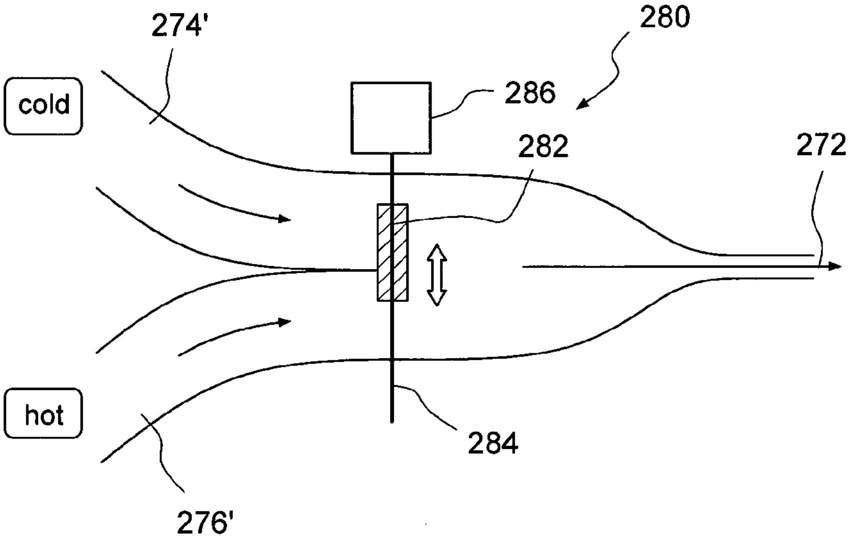


Fig. 18a

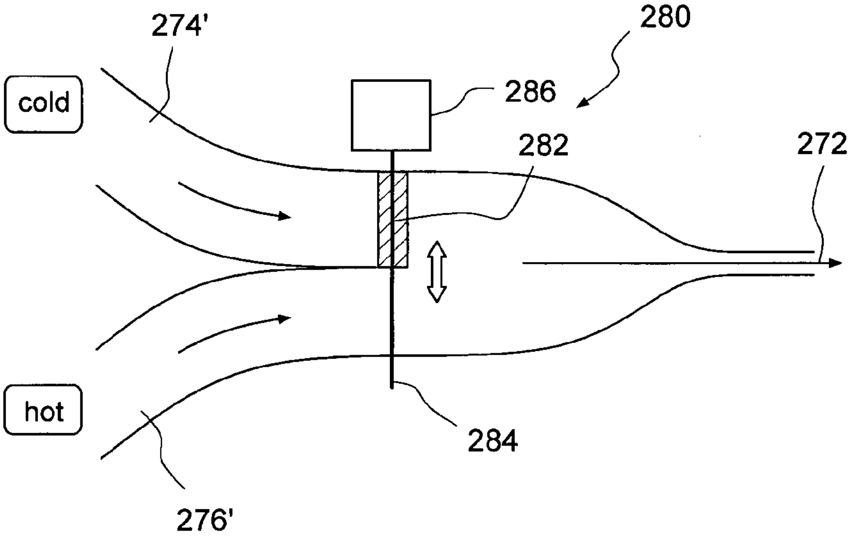
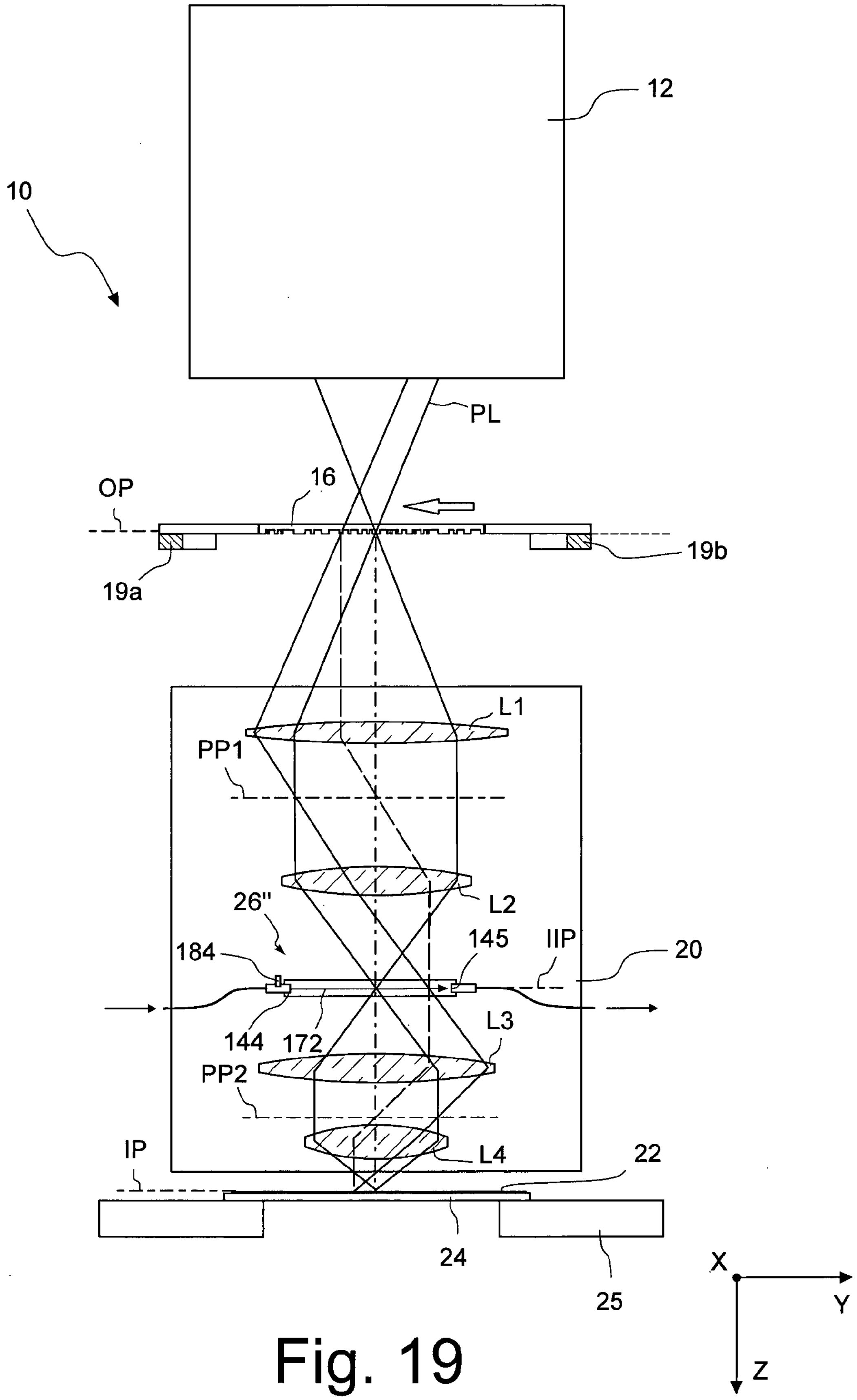


Fig. 18b


12
10
PL
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16
19a
19b
L1
PP1
L2
26"
184
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IIP
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144
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L3
PP2
L4
IP
22
24
25
X
Y
Z

Fig. 19

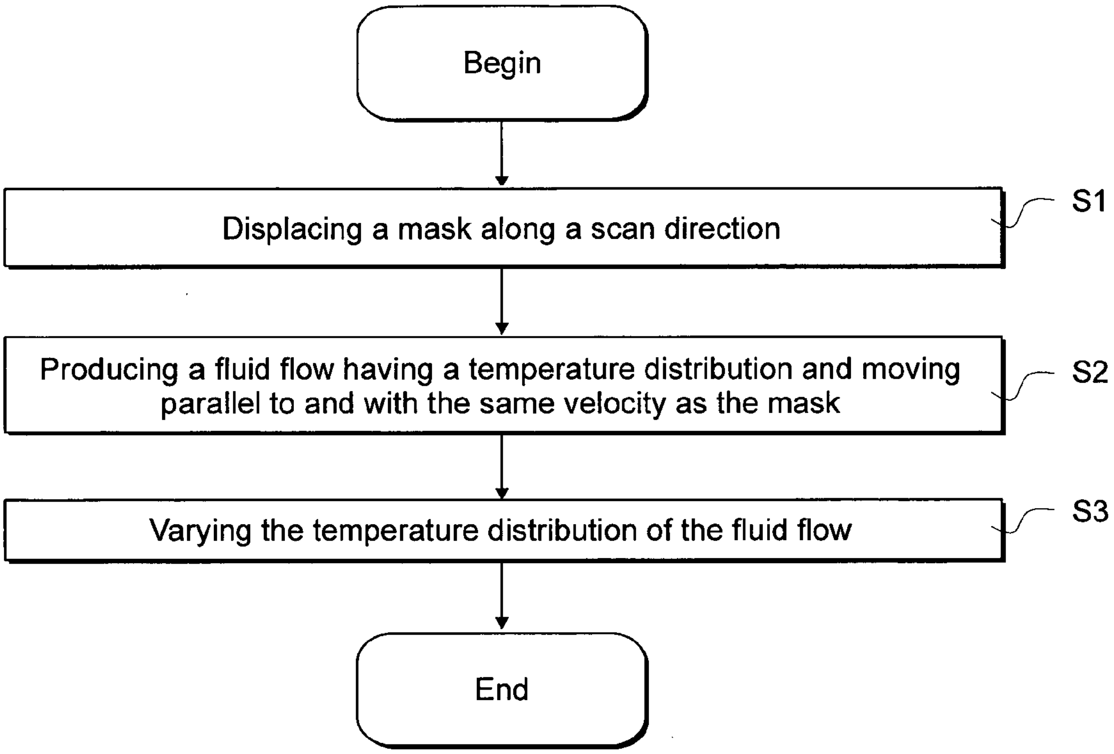
Begin
Displacing a mask along a scan direction
S1
Producing a fluid flow having a temperature distribution and moving parallel to and with the same velocity as the mask
S2
Varying the temperature distribution of the fluid flow
S3
End

Fig. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/002351

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 G02B27/00
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 G02B

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

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/016331 A1 (EXLER MATTHIAS [DE] ET AL) 17 January 2013 (2013-01-17) cited in the application	1,8-12, 19-22
Y	paragraphs [0027] - [0029], [0078] - [0110]; figures 1-6 -----	2-7, 13-18
Y	EP 0 823 662 A2 (NIPPON KOGAKU KK [JP]) 11 February 1998 (1998-02-11) page 6, line 38 - page 10, line 40; figure 1A -----	2-7, 13-18
A	US 2009/040495 A1 (SCHWAB MARKUS [DE]) 12 February 2009 (2009-02-12) paragraphs [0013], [0046] - [0055]; figures 1,2 -----	1-22

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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