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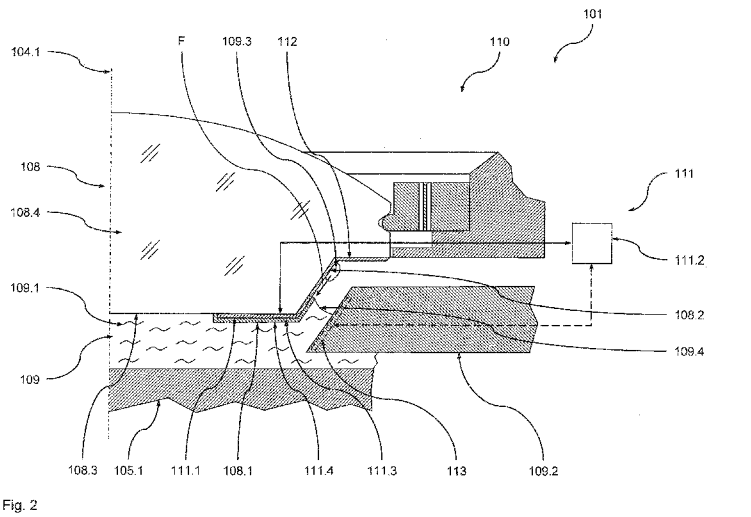

Fig. 2

(57) **Abstract**: The present invention relates to an optical arrangement for use in an optical imaging process comprising an optical element (108), an immersion zone (109) and a liquid repelling device (111). During the optical imaging process, the immersion zone is located adjacent to the optical element and is filled with an immersion liquid (109.1). The optical element has a first surface region (108.1) and a second surface region (108.2), the first surface region, during the optical imaging process, being wetted by the immersion liquid. The liquid repelling device, at least temporarily during the optical imaging process, generates an electrical field in the region of the second surface, the electrical field being adapted to cause a repellent force on parts of the immersion liquid being responsive to the electrical field and inadvertently contacting the second surface region. The repellent force has a direction to drive away the parts of the immersion liquid from the second surface region.

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OPTICAL IMAGING WITH REDUCED IMMERSION LIQUID EVAPORATION EFFECTS

BACKGROUND OF THE INVENTION

The present invention relates to an optical imaging arrangement. The invention may be used in the context of microlithography used for fabricating microelectronic circuits. Thus, it further relates to an optical imaging device which, among others, may be implemented using such an optical imaging arrangement.

Especially in the area of microlithography, apart from the use of components having a high precision, it is necessary to keep the position and the geometry of the components of the imaging device, e.g. the optical elements such as lenses, mirrors and gratings, unchanged during operation to the highest possible extent in order to achieve a correspondingly high imaging quality. The tough requirements with respect to accuracy (lying in the magnitude of a few nanometers or below) are none the less a consequence of the permanent need to reduce the resolution of the optical systems used in fabricating microelectronic circuitry in order to push forward miniaturization of the microelectronic circuitry to be produced.

In order to achieve an increased resolution either the wavelength of light used may be reduced as it is the case with systems working in the extreme UV (EUV) range at working wavelengths in the area of 5 nm to 20 nm (typically at about 13 nm) or the numerical aperture of the projection system used may be increased. One possibility to remarkably increase the numerical aperture above the value 1 is realized in so-called immersion systems, wherein an immersion medium having a refractive index larger than 1 is typically placed between the last optical element of the projection system and the substrate to be exposed. A further increase in the numerical aperture is possible with optical elements having a particularly high refractive index.

It will be appreciated that, in a so-called single immersion system, the immersion element (i.e. the optical element at least in part contacting the immersion medium in the immersed state) typically is the last optical element located closest to the substrate to be exposed. Here, the immersion medium typically contacts this last optical element and the substrate. In a so-called double immersion system, the immersion element does not necessarily have to be the last optical element, i.e. the optical element located closest to the substrate. In such double or multiple immersion systems, and immersion element may also be separated from the substrate by one or more further optical elements. In this case, the immersion medium the immersion element is at least partly immersed in may be placed, for example, between two optical elements of the optical system.

With the reduction of the working wavelength as well as with the increase of the numerical aperture not only the requirements with respect to the positioning accuracy and the dimensional accuracy of the optical elements used become more strict throughout the entire operation. Of course, the requirements with respect to the minimization of imaging errors of the entire optical arrangement increase as well.

The deformations of the respective optical element and the imaging errors resulting therefrom are of special importance in this context. More specifically, it has turned out that evaporation effects of the immersion liquid contacting the optical element may introduce a considerable thermal disturbance into the optical element leading to relatively high local temperature gradients within the optical element. These high local temperature gradients resulting in considerable stresses introduced into the optical element which in turn will lead to increased imaging errors.

These evaporation effects are especially undesired at (ideally) dry areas of the immersion element which, under ideal conditions, should not be wetted by the immersion medium. However, since under real operating conditions the substrate to be exposed at certain points in time has to execute comparatively fast relative movements with respect to the immersion element, kinetic energy is transferred to the immersion medium leading to a certain sloshing movement of the immersion bath. This sloshing movement leads to an inadvertent wetting of these dry areas with parts of the immersion medium such as thin immersion liquid films or immersion liquid splashes etc. These typically randomly distributed and hardly predictable films or splashes are prone to easily evaporate leading to the undesired result on the imaging errors as outlined above.

To solve this problem it has been proposed to provide hydrophobic coatings at these dry areas of the immersion element to reduce the amount of immersion liquid which may contact the immersion element sufficiently long to evaporate and, thus, introduce a noticeable thermal disturbance into the immersion element. However, despite their hydrophobic properties, the use of such coatings has to rely on the gravitational force acting on the immersion liquid splashes or films to provide rapid removal of the immersion medium from the dry areas. Thus, particularly under unfavorable geometric conditions, these hydrophobic coatings may not be sufficient to provide rapid removal of the immersion medium prior to noticeable evaporation.

BRIEF SUMMARY OF THE INVENTION

It is thus an object of the present invention to provide an optical arrangement and an optical imaging device, respectively, not showing the disadvantages outlined above or at least showing them to a lesser degree. It is a further object of the present invention to at least reduce such immersion liquid evaporation effects and, consequently, to improve imaging quality.

The present invention is based on the finding that an improved reduction of the effects of immersion liquid evaporation may be achieved by using an electrical field to which the immersion liquid is responsive in such a manner that a repellent force is exerted at least on the parts of the immersion liquid inadvertently contacting the (ideally) dry areas of the immersion element. Using the electrical field the repellent force may easily be adjusted to quickly drive the undesired parts of the immersion liquid away from the dry areas. In particular, this repellent force may be achieved irrespective of the spatial orientation of the dry area. Thus, even horizontally oriented dry areas may be easily cleared from such immersion liquid films or splashes. In other words, using the invention, clearance from such immersion liquid films or splashes may even be achieved under conditions where gravity based solutions typically do not provide the desired result.

It will be appreciated that gravity may assist the repellent force provided by the electrical field used according to the present invention. In other words, it is sufficient that the repellent force resulting from the electrical field triggers or induces, respectively, a motion of the immersion liquid parts to such an extent that further motion of the undesired immersion liquid parts away from the dry area is at least assisted or, beyond a certain point, predominantly or even fully provided by gravity.

An object of the present invention is thus an optical arrangement for use in an optical imaging process comprising an optical element, an immersion zone and a liquid repelling device. During the optical imaging process, the immersion zone is located adjacent to the optical element and is filled with an immersion liquid. The optical element has a first surface region and a second surface region, the first surface region, during the optical imaging process, being wetted by the immersion liquid. The liquid repelling device, at least temporarily during the optical imaging process, generates an electrical field in the region of the second surface, the electrical field being adapted to cause a repellent force on parts of the immersion liquid being responsive to the electrical field and inadvertently contacting the second surface region. The repellent force has a direction to drive away the parts of the immersion liquid from the second surface region. Thereby contact time between the second surface region and the parts of the immersion liquid is at least shortened leading to a reduction of the undesired evaporation effects as outlined above.

A further object of the present invention is an optical element for use in an optical imaging process comprising an optical element body, a first surface region and a second surface region, the first surface region being adapted to be wetted, during the optical imaging process, by an immersion liquid responsive to an electrical field. At least one electrically conductive element is mechanically connected to the optical element body in the region of at least one of the first surface region and the second surface region, the at least one electrically conductive element being adapted to participate in generating the electrical field.

A further object of the present invention is an optical imaging device, in particular for microlithography, comprising an illumination device, a mask device for receiving a mask comprising a projection pattern, an optical projection device comprising an optical element group and a substrate device for receiving a substrate. The illumination device illuminates the projection pattern while the optical element group projects the projection pattern onto the substrate. The optical projection device further comprises an optical arrangement according to the present invention.

A further object of the present invention is a method of reducing liquid evaporation effects at a surface of an optical element during an optical imaging process comprising providing the optical element and an immersion liquid, the optical element having a first surface region and a second surface region, the first surface region, during the optical imaging process, being wetted by the immersion liquid. At least temporarily during the optical imaging process, an electrical field is generated in the region of the second surface, the electrical field causing a repellent force on parts of the immersion liquid being responsive to the electrical field and inadvertently contacting the second surface region. The repellent force has a direction to drive away the parts of the immersion liquid from the second surface region.

Further objects and preferred embodiments of the invention become apparent from the dependent claims and the following description of preferred embodiments given with reference to the appended drawings, respectively. All combinations of the features disclosed, whether explicitly recited in the claims or not, are within the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of a preferred embodiment of the optical imaging device according to the invention using which the preferred embodiment of the method of reducing liquid evaporation effects at a surface of an optical element according to the invention may be executed;

Figure 2 is a schematic partial section of a part of the imaging device of Figure 1;

Figure 3 is a block diagram of a preferred embodiment of the method of reducing liquid evaporation effects at a surface of an optical element according to the invention which may be executed with the optical imaging device of Figure 1;

Figure 4 is a schematic partial section of a part of a further preferred embodiment of the optical imaging device according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

First embodiment

In the following, a first preferred embodiment of the optical imaging device according to the invention comprising a preferred embodiment of the optical arrangement according to the invention will be described with reference to the Figures 1 to 3.

Figure 1 is a schematic representation of a preferred embodiment of the optical imaging device according to the invention in the form of a microlithography device 101 operating with light in the UV range having a wavelength of 193 nm.

The microlithography device 101 comprises an illumination system 102, a mask device with a mask table 103, an optical projection system in the form of an objective 104 having an optical axis 104.1 and a substrate device 105. In an exposure or optical imaging process performed with the microlithography device 101 the illumination system 102 illuminates a mask 103.1 arranged on the mask table 103 with a projection light beam (not shown in further detail) having a wavelength of 193 nm. A projection pattern is formed on the mask 104.3 which is projected by the projection light beam via the optical elements arranged within the objective 104 onto a substrate in the form of a wafer 105.1 arranged on a wafer table 105.2 of the substrate device 105.

The objective 104 comprises an optical element group 106 formed by a series of optical elements 107, 108. The optical elements 107, 108 are held within the housing 104.2 of the objective 104. Due to the working wavelength of 193 nm the optical elements 107, 108 are refractive optical elements such as lenses or the like. The last optical element 108 located closest to the wafer 105.1 during the optical imaging process is a so called closing element or last lens element.

The microlithography device 101 is an immersion system. Thus, in an immersion zone 109, a liquid immersion medium 109.1, for example highly purified water or the like, is arranged between the wafer 105.1 and the last lens element 109. Within the immersion zone 109 there is provided an immersion bath of the immersion medium 109.1 on the one hand downwardly delimited at least by the part of the wafer 105.1 to be actually exposed. The lateral limitation on the immersion bath is provided at least partially by an immersion frame 109.2 (typically also called an immersion hood). At least the part of the last lens element 108 optically used during exposure and lying on the outer side of the objective 104 is immersed in the immersion bath such that the last lens element 108 is an immersion element in the sense of the present invention. Thus, the path of the light exiting from the last lens element 108 between the last lens element 108 and the wafer 105.1 is located exclusively within the immersion medium 109.1.

Due to the refractive index of the immersion medium 109.1 lying above the value 1 a numerical aperture NA > 1 is achieved and the resolution is enhanced with respect to a conventional system with a gas atmosphere between the last lens element and the wafer.

Figure 2, in a schematic partial sectional view of a part of the microlithography device 101 in the region of the immersion element 108, shows a preferred embodiment of the optical arrangement 110 according to the invention. As can be seen best from Figure 2, the immersion element 108 (forming part of the optical arrangement 110) has a first surface region 108.1 which is contacted and, thus, wetted by the immersion liquid 109.1 (also forming part of the optical arrangement 110) during the optical imaging process.

Consequently, in the following, this first surface region 108.1 is also called the wet surface region of the immersion element 108.

Furthermore, the immersion element 108 has a second surface region 108.2 which is located adjacent to the first surface region 108.1 and, under ideal or static conditions during the optical imaging process, should not be contacted by the immersion bath. Consequently, in the following, this second surface region 108.2 is also called a (ideally) dry surface region of the immersion element.

However, since under real operating conditions of the microlithography device 101, the wafer 105.1 to be exposed at certain points in time has to execute comparatively fast relative movements with respect to the immersion element 108 (in the x- and y-direction), kinetic energy is transferred to the immersion medium 109.1 leading to a certain sloshing movement of the immersion bath. This sloshing movement leads to an inadvertent wetting of the dry surface region 108.2 with parts of the immersion medium such as thin immersion liquid films, immersion liquid splashes or immersion liquid drops etc. as it is indicated in an exemplary way by the immersion liquid drop 109.3 in Figure 2. These typically randomly distributed and hardly predictable films or splashes are prone to easily evaporate leading to high local temperature gradients within the immersion element 108 and, consequently, to the undesired effect of increasing the imaging errors introduced into the imaging process via the immersion element 108 as has been outlined in detail above.

In order to at least reduce these evaporation effects the optical arrangement 111 comprises a liquid repelling device 111. The liquid repelling device 111 serves to exert a repellent force F on the parts of the immersion liquid 109.1 inadvertently contacting the dry surface region 108.2 such as, for example, the immersion liquid drop 109.3. As can be seen from Figure 2, this repellent force F has a direction which helps to quickly drive the drop 109.3 inadvertently contacting the dry surface region 108.2 away from the dry surface region 108.2. By this means, the contact time between the dry surface region 108.2 and the drop 109.3 is at least shortened leading to a reduced local cooling of the immersion element 108 (caused by the evaporation of parts of the drop 109.3 or even the entire drop 109.3).

The liquid repellent device 111, in the embodiment shown in Figure 2, achieves this repellent force F via a field generating element in the form of an electrically conductive element 111.1 located in the wet surface region 108.1. The electrically conductive element 111.1 is formed by a layer of a coating formed on the outer surface 108.3 of the optical element body 108.4 of the immersion element 108. The coating 111.1 is made of an electrically conductive material comprising (exclusively or in an arbitrary combination) chromium (Cr), aluminium (Al), titanium (Ti), hafnium (Hf), nickel (Ni) or any other electrically conductive material which is approved for use in the specific optical imaging application performed with the device 101 (i.e. here: any other electrically conductive material which is approved for use in microlithography applications).

The electrically conductive element 111.1 generates a first electrical field E1 to which the immersion liquid 109.1 is responsive leading to the repellent force F acting on the drop 109.3. In the embodiment shown, the electrical field E1 is generated by electrostatically charging the electrically conductive element 111.1. This is done via a first field generating device 111.2 that temporarily electrically contacts the electrically conductive element 111.1 in order to provide the electrostatic charge at the electrically conductive element 111.1.

The polarity of the electrostatic charge at the electrically conductive element 111.1 depends on the immersion liquid and the repellent force F to be exerted on the drop 109.3. In the embodiment shown in Figure 2, with the electrically conductive element 111.1 being arranged in the wet surface region 108.1, the repellent force F is provided by an attractive force acting between the drop 109.3 and the electrically conductive element 111.1 and provoked by the electrostatic charge of the electrically conductive element 111.1.

In the embodiment shown in Figure 2, the electrically conductive element 111.1 is provided with a negative (or positive) electrical charge such that the desired repellent force F is achieved in the interaction between the inhomogeneous electrostatic field (showing a field gradient between 100 V/m^2 and 10000 V/m^2, preferably between 500 V/m^2 and 5000 V/m^2) produced by the electrically charged element 111.1 and the immersion liquid 109.1 which is electrically polarized by the electrostatic field of the electrically charged element 111.1 (i.e. shows an orientation of the electrical dipoles in the highly purified water used as the immersion liquid 109.1 as a result of the field produced by the electrically charged element 111.1).

In this context the following basic considerations apply. An immersion liquid droplet 109.3 sitting on the dry surface region 108.2 and having a radius r = 2 mm is subject to attraction forces A (due to its prevailing surface energy SE of about $80 \cdot 10^{-3}$ N/m resulting from its the surface tension and the interaction with the surface of the surface region 108.2) lying in the order of magnitude of 1 mN according to the equation:

$$A = 2 \cdot \pi \cdot r \cdot SE = 2 \cdot \pi \cdot (2 \cdot 10^{-3} m) \cdot (80 \cdot 10^{-3} \frac{N}{m}) \approx 1 \cdot 10^{-3} N \quad (1)$$

The static frictional forces to be overcome lie in the order of magnitude of 1 mN to $1 \cdot 10^{-3}$ mN.

A point-shaped electric charge Q generates an electrical field E at a distance d according to the following equation:

$$E = \frac{Q}{4 \cdot \pi \cdot \varepsilon_0} \cdot \frac{1}{r^2}, \quad (2)$$

wherein $\varepsilon_0 = 8.85 \cdot 10^{-12}$ C/(V·m) is the electric constant (also referred to as vacuum permittivity). Accordingly, the electric field gradient dE/dr is calculated according to the following equation:

$$\frac{dE}{dr} = \frac{Q}{2 \cdot \pi \cdot \varepsilon_0} \cdot \frac{1}{r^3}. \quad (3)$$

In a rough approximation, a water droplet in an electric field E undergoes an electric polarization P according to the following equation:

$$P = \varepsilon_0 \cdot (\varepsilon_r - 1) \cdot E, \quad (4)$$

wherein ε_r is the relative static permittivity (also referred to as dielectric constant). Thus, with a relative static permittivity $\varepsilon_r = 80$ for a water droplet, using equations (2) to (4) the force on such a electrically polarized water droplet is calculated according to the following equation:

$$F = P \cdot \frac{dE}{dr} = \frac{Q^2 \cdot (\varepsilon_r - 1)}{8 \cdot \pi \cdot \varepsilon_0 \cdot r^5}. \quad (5)$$

Thus, a point-shaped electric charge of Q = 1 nC (=$1,9 \cdot 10^{10}$ e, with e being the elementary charge), at a distance d = 0.1 m, provokes an electric field E = 900 V/m and an electric field gradient dE/dr = $1.8 \cdot 10^4$ V/m^2. Thus, the water droplet, in a first approximation, undergoes a dipole moment of $6.3 \cdot 10^{-7}$ Cm. The resulting force exerted on the water droplet is thus

$F = 11 \cdot 10^{-3}$ N. Thus, it is preferred to have a field gradient between 100 V/m^2 and 10000 V/m^2, preferably between 500 V/m^2 and 5000 V/m^2.

However, it will be appreciated that, with other embodiments of the invention, the immersion medium itself may be provided with a corresponding electrical charge (by suitable means) in order to achieve the desired repellent force F. Apparently, the electrical charge of the electrically conductive element is then selected as a function of the electrical charge of the immersion medium (and vice versa).

In this context the following basic considerations apply. In an electrically charged immersion medium the force F acting on the droplet having an electric charge Q in an electric field E is calculated according to the following equation:

$$F = E \cdot Q . \qquad (6)$$

Thus, in order to achieve a force $F = 1 \cdot 10^{-3}$ N in an electric field $E = 1 \cdot 10^{3}$ V/m, an electric charge of $Q = 1 \cdot 10^{-6}$ C is required.

It will be appreciated that the electrical charge of the electrically conductive element 111.1 may be provided only once provided that no substantial loss in the charge is to be expected over the lifetime of the system. However, as shown in Figure 2, the field generating device 111.2 is adapted to electrically contact the electrically conductive element 111.1 from time to time (e.g. between the exposure of different wafers 105.1) in order to maintain the electrostatic charge at the electrically conductive element 111.1 at the desired level.

In order to prevent discharge of the electrically conductive element 111.1 an electrically insulating element 111.3 is provided on the third surface region 111.4 of the electrically conductive element 111.1 facing the immersion liquid 109.1. The electrically insulating element 111.3 may be formed from any suitable electrically insulating material which is approved for use in the specific optical imaging application performed with the device 101 (i.e. here: any other electrically insulating material which is approved for use in microlithography applications).

The electrically insulating element 111.3 is formed by a layer of a coating formed on the outer surface 111.4 of the electrically conductive element 111.1. The coating 111.3 is made of an electrically insulating material comprising (exclusively or in an arbitrary combination) silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), hafnium oxide (HfO_2), tantalum pentoxide (Ta_2O_5) or any other suitable electrically insulating material.

It will be appreciated that the silicon dioxide (SiO_2) also has the advantage that it is a hydrophilic material leading to good wetting properties at the wet surface region 108.1. However, it will be appreciated that, with other embodiments of the invention, a combination of at least one electrically insulating layer and at least one hydrophilic layer may be chosen for the electrically insulating element.

It will be further appreciated that, with other embodiments of the invention, the electrically conductive element may also be fully embedded in such an electrically insulating element in order to prevent discharge to the largest possible extent.

The electrically conductive element 111.1 ends in the region where the free surface 109.4 of the immersion bath is ideally located, i.e. at the transition between the wet surface region 108.1 and the dry surface region 108.2. Thus, a good assistance of the removal of the immersion liquid parts from the dry surface region 108.2 by the repellent force F is achieved.

As can be seen from Figure 2, in the embodiment shown, the optical element body 108.4 is further provided with a hydrophobic coating 112 in the dry surface region 108.2 further promoting removal of the inadvertent immersion liquid parts from the dry surface region 108.2. However, with other embodiments of the invention, such a hydrophobic coating may also be omitted.

It will be appreciated that, with other embodiments of the invention, instead or in addition to the electrically conductive element 111.1 an electrically conductive element (generating or contributing to the electric field provoking the repellent force F) may also be provided at a location other than the immersion element, e.g. at the immersion frame 109.2 as it is indicated by the dashed contour 113 in Figure 2. The implementation and principle of operation of such an electrically conductive element 113 is identical to the one of the electrically conductive element 111.1 such that it is here only referred to the explanations given above.

It will be appreciated that, with other embodiments of the invention, instead of a single electrically conductive element 111.1 a plurality of electrically conductive elements may be used in the liquid repelling device. Furthermore, different sizes and/or shapes and/or materials (in a virtually arbitrary combination) may be chosen for these electrically conductive elements depending, in particular, on the electrical field to be generated.

It will be further appreciated that the repellent force F may be achieved irrespective of the spatial orientation of the dry surface region 108.2. Thus, even horizontally oriented dry surface regions may be easily cleared from such immersion liquid drops 109.3. In other words, using the invention, clearance from such immersion liquid films, splashes or drops may even be achieved under conditions where gravity based solutions typically do not provide the desired result.

It will be further appreciated that gravity may assist the repellent force F provided by the liquid repelling device 110 according to the present invention. In other words, it is sufficient that the repellent force F triggers or induces, respectively, a motion of the immersion liquid parts 109.3 to such an extent that further motion of the undesired immersion liquid parts 109.3 away from the dry surface region 108.2 is at least assisted or, beyond a certain point, predominantly or even fully provided by gravity.

It will be further appreciated that, in addition to promoting removal of the drop 109.3 from the dry surface, the liquid repelling device 111, due to the repellent force F generated, also helps to prevent formation of such immersion liquid parts at the dry surface region as a result of the sloshing movement of the immersion liquid.

Figure 3 shows a block diagram of a preferred embodiment of an optical imaging method which may be executed with the microlithography device 101 and includes a method of reducing liquid evaporation effects at a surface of an optical element during an optical imaging process according to the invention.

First, in a step 114.1 execution of the method starts. In a step 114.2 the components of the microlithography device 101 are mutually positioned with respect to each other such that the configuration described above is achieved.

In a step 114.3 at least a part of the projection pattern on the mask 103.1 is projected onto the wafer 105.1 in the manner as it has been described above. In a step 114.3, in parallel to this projection, the liquid repellent force F is generated by means of the liquid repelling device 111 as it has been described above.

In a step 114.5 it is checked if execution of the method is to be stopped. If this is the case, execution of the method is stopped in a step 114.6. Otherwise it is jumped back to step 114.3.

Second embodiment

In the following a second preferred embodiment of an optical arrangement 210 according to the invention will be described with reference to Figures 1, 3 and 4. The optical arrangement 210 may replace the optical arrangement 110 in the microlithography device 101 of Figure 1. The optical arrangement 210 in its basic design and functionality largely corresponds to the optical arrangement 110 such that it will be mainly referred to the differences only. In particular, similar components are given the same reference numerals raised by the amount 100. In case nothing else is stated in the following with respect to the properties of such components it is here referred to the explanations given above.

Figure 4, in a schematic partial sectional view similar to Figure 2, shows the optical arrangement 210. As can be seen best from Figure 4, the immersion element 108 (forming part of the optical arrangement 210) again has a wet first surface region 108.1 which is contacted and, thus, wetted by the immersion liquid 109.1 (also forming part of the optical arrangement 210) during the optical imaging process. Furthermore, the immersion element 108 again has a dry second surface region 108.2 which is located adjacent to the first surface region 108.1 and, under ideal or static conditions during the optical imaging process, should not be contacted by the immersion bath.

In order to at least reduce the evaporation effects of immersion liquid films, immersion liquid splashes or immersion liquid drops 109.3 the optical arrangement 211 comprises a liquid repelling device 211. The liquid repelling device 211 serves to exert a repellent force F on the parts of the immersion liquid 109.1 inadvertently contacting the dry surface region 108.2 such as, for example, the immersion liquid drop 109.3. As can be seen from Figure 3, this repellent force F has a direction which helps to quickly drive the drop 109.3 inadvertently contacting the dry surface region 108.2 away from the dry surface region 108.2. By this means, the contact time between the dry surface region 108.2 and the drop 109.3 is at least shortened leading to a reduced local cooling of the immersion element 108 (caused by the evaporation of parts of the drop 109.3 or even the entire drop 109.3).

The liquid repellent device 211, in the embodiment shown in Figure 4, achieves this repellent force F via a field generating element in the form of an electrically conductive element 211.1 located in the dry surface region 108.2. The electrically conductive element 211.1 is formed by a layer of a coating formed on the outer surface 108.3 of the optical element body 108.4 of the immersion element 108. The coating 211.1 is made of an electrically conductive material comprising (exclusively or in an arbitrary combination) chromium (Cr), aluminium (Al), hafnium (Hf), titanium (Ti), nickel (Ni) or any other electrically conductive material which is approved for use in the specific optical imaging application performed with the device 101 (i.e. here: any other electrically conductive material which is approved for use in microlithography applications).

The electrically conductive element 211.1 generates a first electrical field E1 to which the immersion liquid 109.1 is responsive leading to the repellent force F acting on the drop 109.3. In the embodiment shown, the electrical field E1 is generated by electrostatically charging the electrically conductive element 211.1. This is done via a first field generating device 211.2 that temporarily electrically contacts the electrically conductive element 211.1 in order to provide the electrostatic charge at the electrically conductive element 211.1.

The polarity of the electrostatic charge at the electrically conductive element 211.1 depends on the immersion liquid and the repellent force F to be exerted on the drop 109.3. In the embodiment shown in Figure 4, with the electrically conductive element 211.1 being arranged in the dry surface region 108.2, the repellent force F is provided by a repulsive force acting between the drop 109.3 and the electrically conductive element 211.1 and provoked by the electrostatic charge of the electrically conductive element 211.1.

In the embodiment shown in Figure 4, the electrically conductive element 211.1 is provided with a negative (or positive) electrical charge such that the desired repellent force F is achieved in the interaction with an electrical polarity of the immersion liquid 109.1 formed by an orientation of the electrical dipoles in the highly purified water used as the immersion liquid 109.1. This polarity in the immersion liquid 109.1 is achieved via a second electrical field E2 generated by a further, second field generating device 211.5 of the liquid repelling device 211.

However, it will be appreciated that, with other embodiments of the invention, the immersion medium itself may be provided with a corresponding electrical charge (by suitable means) in order to achieve the desired repellent force F. Apparently, the electrical charge of the electrically conductive element is then selected as a function of the electrical charge of the immersion medium (and vice versa).

It will be appreciated that the electrical charge of the electrically conductive element 211.1 may be provided only once provided that no substantial loss in the charge is to be expected over the lifetime of the system. However, as shown in Figure 3, the field generating device 211.2 is adapted to electrically contact the electrically conductive element 211.1 from time to time (e.g. between the exposure of different wafers 105.1) in order to maintain the electrostatic charge at the electrically conductive element 211.1 at the desired level.

In order to prevent discharge of the electrically conductive element 211.1 an electrically insulating element 211.3 is provided on the third surface region 211.4 of the electrically conductive element 211.1 facing the immersion liquid 109.1. The electrically insulating element 211.3 may be formed from any suitable electrically insulating material which is approved for use in the specific optical imaging application performed with the device 101 (i.e. here: any other electrically insulating material which is approved for use in microlithography applications).

The electrically insulating element 211.3 is formed by a layer of a coating formed on the outer surface 211.4 of the electrically conductive element 211.1. The coating 211.3 is made of an electrically insulating material comprising (exclusively or in an arbitrary combination) a hydrophobic material like diamond-like-carbon (DLC) or Teflon-like material or of hydrophilic material like SiO_2, Al_2O_3 or Ta_2O_5 or any other suitable electrically insulating material ultimately covered with an additional hydrophobic material.

It will be appreciated that the electrically insulating material preferably is a hydrophobic material leading to good liquid removal properties at the dry surface region 108.2. However, it will be appreciated that, with other embodiments of the invention, a combination of at least one electrically insulating layer and at least one hydrophobic layer may be chosen for the electrically insulating element.

It will be further appreciated that, with other embodiments of the invention, the electrically conductive element may also be fully embedded in such an electrically insulating element in order to prevent discharge to the largest possible extent.

The electrically conductive element 211.1 ends in the region where the free surface 109.4 of the immersion bath is ideally located, i.e. at the transition between the wet surface region 108.1 and the dry surface region 108.2. Thus, a good assistance of the removal of the immersion liquid parts from the dry surface region 108.2 by the repellent force F is achieved.

As can be seen from Figure 4, in the embodiment shown, the optical element body 108.4 is further provided with a hydrophilic coating 212 in the wet surface region 108.1 promoting good wetting of the wet surface 108.1. However, with other embodiments of the invention, such a hydrophilic coating may also be omitted.

It will be appreciated that, with other embodiments of the invention, instead or in addition to the electrically conductive element 211.1 an electrically conductive element (generating or contributing to the electric field provoking the repellent force F) as it has been described in the context of the first embodiment may also be provided as it is indicated by the dashed contour 214 in Figure 4. The implementation and principle of operation of such an electrically conductive element 214 is identical to the one of the electrically conductive element 111.1 such that it is here only referred to the explanations given above.

It will be appreciated that, with other embodiments of the invention, instead of a single electrically conductive element 211.1 a plurality of electrically conductive elements may be used in the liquid repelling device. Furthermore, different sizes and/or shapes and/or materials (in a virtually arbitrary combination) may be chosen for these electrically conductive elements depending, in particular, on the electrical field to be generated.

It will be further appreciated that the repellent force F may be achieved irrespective of the spatial orientation of the dry surface region 108.2. Thus, even horizontally oriented dry surface regions may be easily cleared from such immersion liquid drops 109.3. In other words, using the invention, clearance from such immersion liquid films, splashes or drops may even be achieved under conditions where gravity based solutions typically do not provide the desired result.

It will be further appreciated that gravity may assist the repellent force F provided by the liquid repelling device 210 according to the present invention. In other words, it is sufficient that the repellent force F triggers or induces, respectively, a motion of the immersion liquid parts 109.3 to such an extent that further motion of the undesired immersion liquid parts 109.3 away from the dry surface region 108.2 is at least assisted or, beyond a certain point, predominantly or even fully provided by gravity.

It will be appreciated that the methods described above with reference to Figure 3 may also be executed with the second embodiment such that it is here only referred to the explanations given above.

In the foregoing, the present invention has been described by means of examples where the electrical field provoking the repellent force is an electrostatic field. However, it will be appreciated that the invention may also be implemented using electrodynamic fields to which the immersion liquid is responsive generating the desired repellent force F.

In the foregoing, the present invention has been described by means of examples wherein the optical element group consists of refractive optical elements exclusively. However, it is to be mentioned here that the invention, in particular in the case of performing the imaging process at different wavelengths, may of course be used with optical element groups that comprise, alone or in an arbitrary combination, refractive, reflective or diffractive optical elements.

Furthermore, it is to be mentioned that, in the foregoing, the present invention has been described by means of an example in the area of microlithography. However, it will be appreciated that the present invention may also be used for any other application and imaging process, respectively.

* * * * *

WHAT IS CLAIMED IS

1. An optical arrangement for use in an optical imaging process comprising
   - an optical element,
   - an immersion zone and
   - a liquid repelling device;
   - said immersion zone, during said optical imaging process, being located adjacent to said optical element and being filled with an immersion liquid;
   - said optical element having a first surface region and a second surface region;
   - said first surface region, during said optical imaging process, being wetted by said immersion liquid; wherein
   - said liquid repelling device, at least temporarily during said optical imaging process, generating an electrical field in the region of said second surface;
   - said electrical field being adapted to cause a repellent force on parts of said immersion liquid being responsive to said electrical field and inadvertently contacting said second surface region;
   - said repellent force having a direction to drive away said parts of said immersion liquid from said second surface region.

2. The optical arrangement according to claim 1, wherein said electrical field is an electrostatic field.

3. The optical arrangement according to claim 1 or 2, wherein
   - said liquid repelling device comprises at least one electrically conductive element;
   - said at least one electrically conductive element being located adjacent to said optical element.

4. The optical arrangement according to claim 3, wherein said at least one electrically conductive element is one of mechanically connected to said optical element and mechanically connected to a further component other than said optical element.

5. The optical arrangement according to claim 4, wherein

- said at least one electrically conductive element is located in the region of said first surface region;
- said electrical field being configured such that said repellent force acts as an attractive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

6. The optical arrangement according to claim 5, wherein

- said at least one electrically conductive element has a third surface region;
- said third surface region, during said imaging process, facing said immersion fluid;
- at least one cover element covering at least said third surface region;
- said at least one cover element being at least one of electrically insulating and hydrophilic.

7. The optical arrangement according to claim 6, wherein said at least one cover element comprises at least one material selected from a material group consisting of a silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), hafnium oxide (HfO_2), tantalum pentoxide (Ta_2O_5).

8. The optical arrangement according to any one of claims 4 to 7, wherein

- said at least one electrically conductive element is located in the region of said second surface region;
- said electrical field being configured such that said repellent force acts as a repulsive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

9. The optical arrangement according to claim 8, wherein

- said at least one electrically conductive element has a third surface region;

- said a third surface region, during said imaging process, facing said immersion fluid;
- at least one cover element covering at least said third surface region;
- said at least one cover element being at least one of electrically insulating and hydrophobic.

10. The optical arrangement according to any one of claims 3 to 9, wherein said at least one electrically conductive element comprises at least one material selected from a material group consisting of chromium (Cr), aluminium (Al), hafnium (Hf), titanium (Ti), nickel (Ni)

11. The optical arrangement according to any one of claims 3 to 10, wherein
- said liquid repelling device comprises at least one electrical field generating device,
- said electrical field generating device at least temporarily electrically contacting said at least one electrically conductive element.

12. The optical arrangement according to any one of claims 1 to 11, wherein
- said electrical field is a first electrical field and
- said liquid repelling device comprises at least one electrical field generating device,
- said electrical field generating device, at least temporarily during said optical imaging process, generating a second electrical field;
- said second electrical field, to at least enhance a responsiveness of said immersion liquid to said first electrical field, providing at least one of a first effect and a second effect;
- said first effect being an electrical polarization of at least said parts of said immersion liquid inadvertently contacting said second surface region;
- said second effect being an electrostatic charge of at least said parts of said immersion liquid inadvertently contacting said second surface region.

13. An optical element for use in an optical imaging process comprising

- an optical element body,
- a first surface region and
- a second surface region;
- said first surface region being adapted to be wetted, during said optical imaging process, by an immersion liquid responsive to an electrical field; wherein
- at least one electrically conductive element being mechanically connected to said optical element body in the region of at least one of said first surface region and said second surface region
- said at least one electrically conductive element being adapted to participate in generating said electrical field.

14. The optical element according to claim 13, wherein said at least one electrically conductive element is electrically charged to generate an electrostatic field as said electrical field.

15. The optical element according to claim 13 or 14, wherein

- said at least one electrically conductive element is located in the region of said first surface region;
- said electrical field being configured such that said repellent force acts as an attractive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

16. The optical element according to claim 15, wherein

- said at least one electrically conductive element has a third surface region;
- said third surface region, during said imaging process, facing said immersion fluid;
- at least one cover element covering at least said third surface region;
- said at least one cover element being at least one of electrically insulating and hydrophilic.

17. The optical element according to claim 16, wherein said at least one cover element comprises at least one material selected from a material group consisting of a silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), hafnium oxide (HfO_2), tantalum pentoxide (Ta_2O_5).

18. The optical element according to any one of claims 13 to 17, wherein
- said at least one electrically conductive element is located in the region of said second surface region;
- said electrical field being configured such that said repellent force acts as a repulsive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

19. The optical element according to claim 18, wherein
- said at least one electrically conductive element has a third surface region;
- said a third surface region, during said imaging process, facing said immersion fluid;
- at least one cover element covering at least said third surface region;
- said at least one cover element being at least one of electrically insulating and hydrophobic.

20. The optical element according to any one of claims 13 to 19, wherein said at least one electrically conductive element comprises at least one material selected from a material group consisting of chromium (Cr), aluminium (Al), hafnium (Hf), titanium (Ti), nickel (Ni).

21. An optical imaging device, in particular for microlithography, comprising
- an illumination device,
- a mask device for receiving a mask comprising a projection pattern,
- an optical projection device comprising an optical element group and
- a substrate device for receiving a substrate;

- said illumination device illuminating said projection pattern;
- said optical element group projecting said projection pattern onto said substrate;
- said optical projection device further comprising an optical arrangement according to any one of claims 1 to 12.

22. A method of reducing liquid evaporation effects at a surface of an optical element during an optical imaging process comprising
- providing said optical element and an immersion liquid;
- said optical element having a first surface region and a second surface region;
- said first surface region, during said optical imaging process, being wetted by said immersion liquid; wherein,
- at least temporarily during said optical imaging process, an electrical field is generated in the region of said second surface;
- said electrical field causing a repellent force on parts of said immersion liquid being responsive to said electrical field and inadvertently contacting said second surface region;
- said repellent force having a direction to drive away said parts of said immersion liquid from said second surface region.

23. The method according to claim 22, wherein said electrical field is an electrostatic field.

24. The method according to claim 22 or 23, wherein
- said electrical field is generated using at least one electrically conductive element;
- said at least one electrically conductive element being located adjacent to said optical element.

25. The method according to claim 24, wherein
- said at least one electrically conductive element is located in the region of said first surface region;

- said electrical field being generated such that said repellent force acts as an attractive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

26. The method according claim 24 or 25, wherein

- said at least one electrically conductive element is located in the region of said second surface region;
- said electrical field being generated such that said repellent force acts as a repulsive force between said parts of said immersion liquid inadvertently contacting said second surface region and said at least one electrically conductive element.

27. The method according to any one of claims 24 to 26, wherein at least temporarily said at least one electrically conductive element is electrically contacted to generate said electrical field.

28. The method according to any one of claims 22 to 27, wherein

- said electrical field is a first electrical field and,
- at least temporarily during said optical imaging process, a second electrical field is generated;
- said second electrical field, to at least enhance a responsiveness of said immersion liquid to said first electrical field, providing at least one of a first effect and a second effect;
- said first effect being an electrical polarization of at least said parts of said immersion liquid inadvertently contacting said second surface region;
- said second effect being an electrostatic charge of at least said parts of said immersion liquid inadvertently contacting said second surface region.

* * * * *

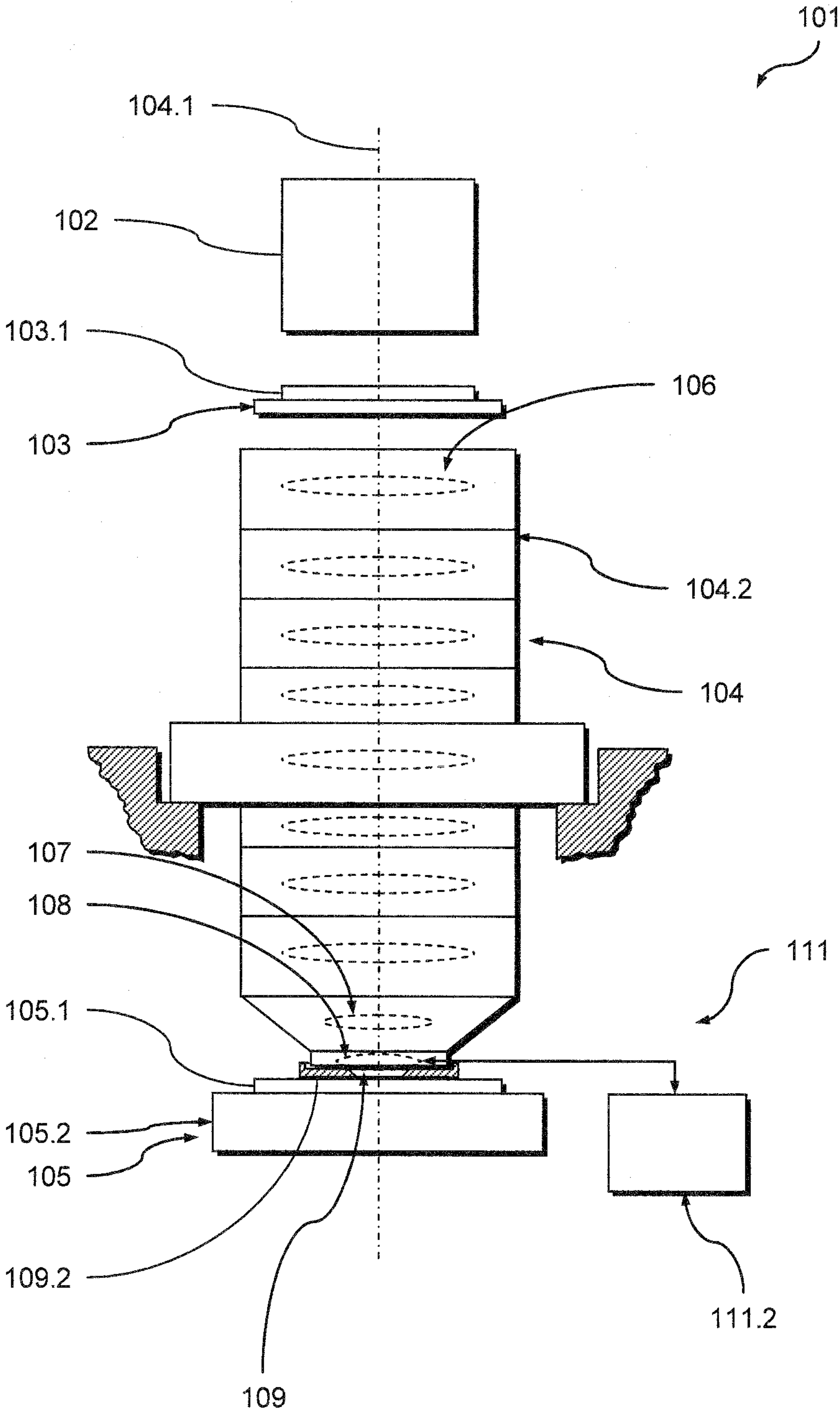
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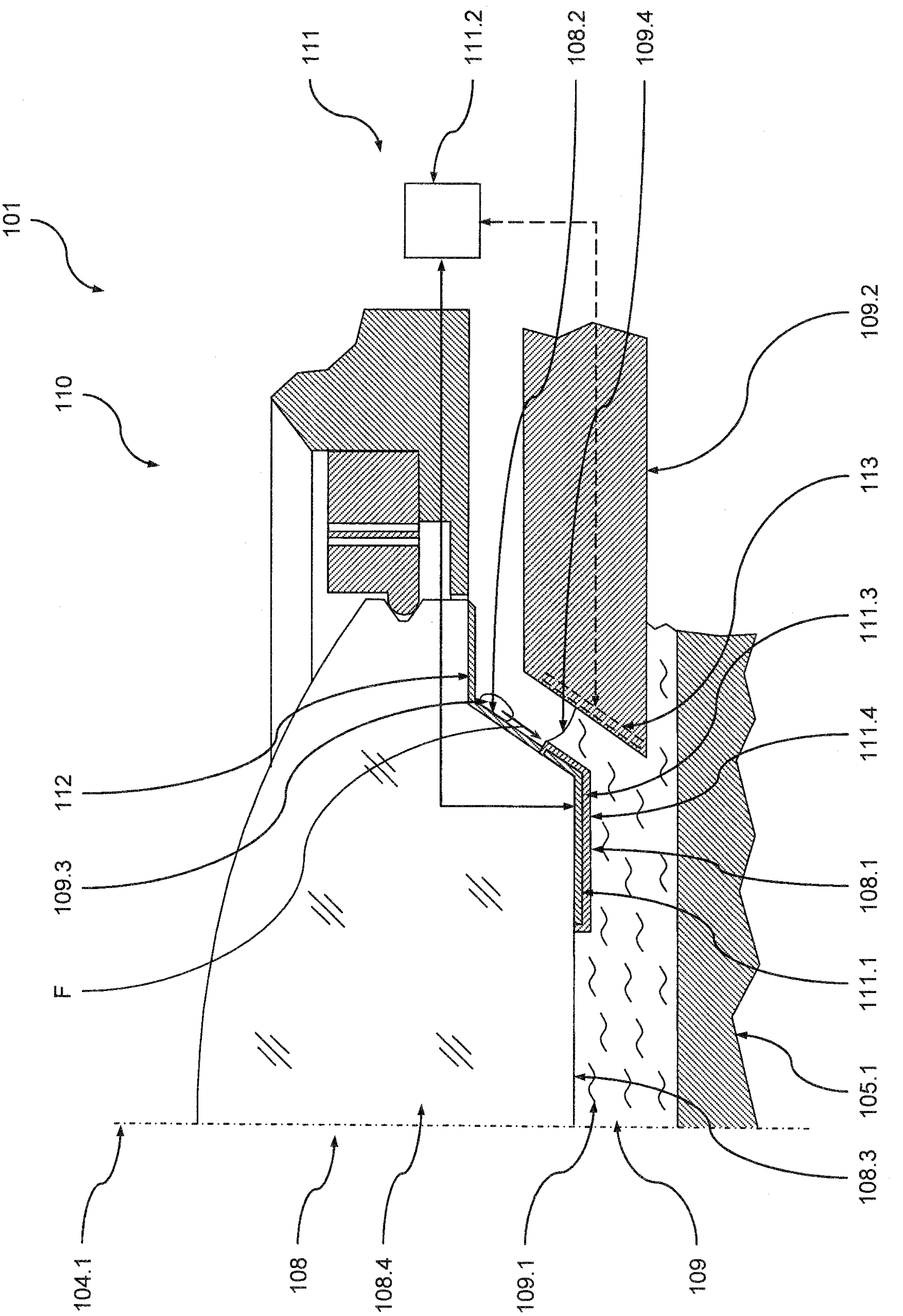
Fig. 1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109.1
109

Fig. 2

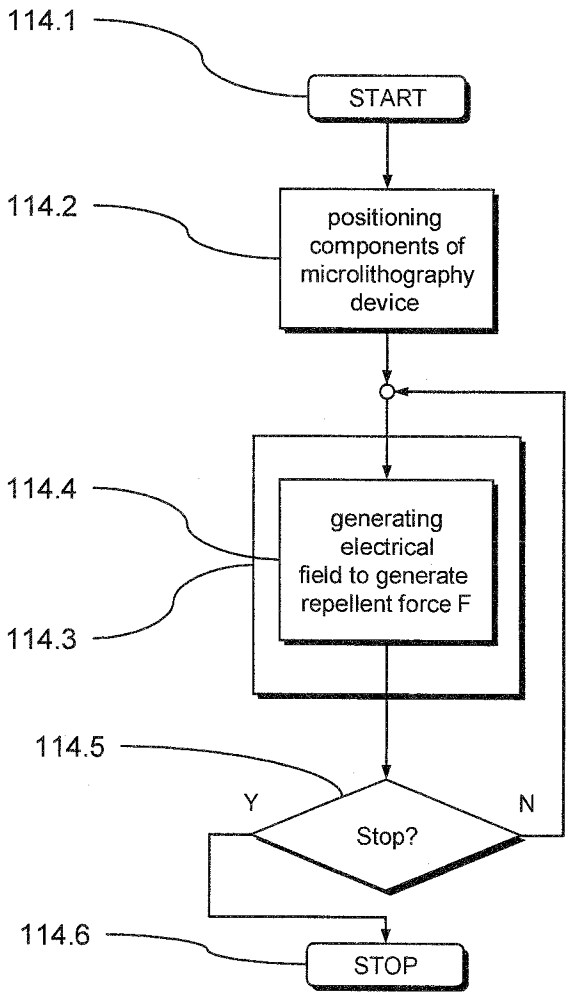
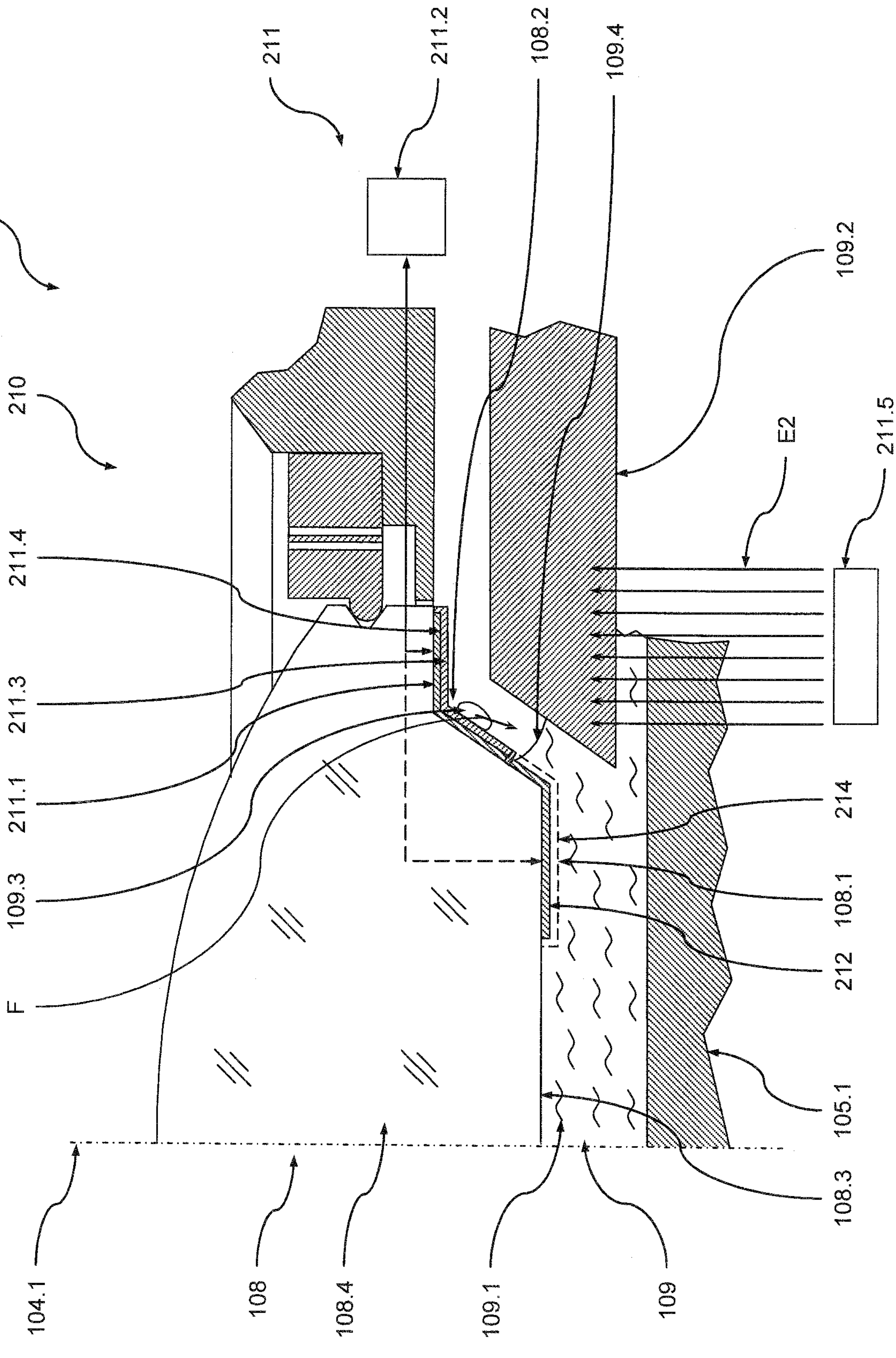

114.1
START
114.2
positioning components of microlithography device
114.4
generating electrical field to generate repellent force F
114.3
114.5
Y
N
Stop?
114.6
STOP

Fig. 3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211.2
108.2
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211.5
211.4
211.3
211.1
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F
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108.1
212
105.1
108.3
104.1
108
108.4
109.1
109

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/056000

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F H01L

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

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

EPO-Internal, 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	WO 2005/081067 A1 (ZEISS CARL SMT AG [DE]; KNEER BERNHARD [DE]; WABRA NORBERT [DE]; GRUNE) 1 September 2005 (2005-09-01) * abstract figures 1-4 page 1, line 3 - line 8 page 12, line 15 - page 17, line 19 -----	13,14, 18-20
A	WO 2008/031576 A1 (ZEISS CARL SMT AG [DE]; SIX STEPHAN [DE]; LILL MICHAEL [DE]; DUESING R) 20 March 2008 (2008-03-20) * abstract figures 1a,1b pages 1,15-21 -----	1,13,21, 22

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[X] Further documents are listed in the continuation of Box C.

[X] 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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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 August 2010	10/08/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Andersen, Ole

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No
PCT/EP2010/056000

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