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(54) Title: METHOD FOR PRODUCING A MIRROR OF A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS

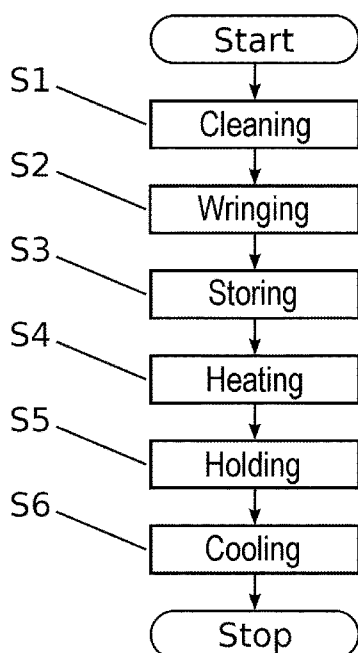


Fig. 5

(57) Abstract: The invention relates to a method for producing a mirror (26) of a microlithographic projection exposure apparatus (1), a first mirror part (27) and a second mirror part (28) being provided, which are in contact in the region of a first connecting surface (29) of the first mirror part (27) and a second connecting surface (30) of the second mirror part (28). For forming a durable connection between the first mirror part (27) and the second mirror part (28), the first mirror part (27) and the second mirror part (28) are heated up to a holding temperature of at least 400°C and are kept at the holding temperature during a holding time. After the holding time has elapsed, the first mirror part (27) and the second mirror part (28) are cooled down to a first cooling temperature at a first cooling rate of a maximum of 100 K/h.

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Method for producing a mirror of a microlithographic projection exposure apparatus

The invention relates to a method for producing a mirror of a microlithographic projection exposure apparatus. The invention also relates to a mirror of a microlithographic projection exposure apparatus, to an illumination optical unit, to a projection optical unit and to a
5 microlithographic projection exposure apparatus.

Microlithographic projection exposure apparatuses are used in particular in the production of semiconductors and generally have an illumination optical unit and a projection optical unit.
10 The illumination optical unit generates from the light of a light source a desired light distribution for the illumination of a reticle, which is often also referred to as a mask. Light should be understood in this case in the general sense of electromagnetic radiation, i.e. there is no restriction to a specific wavelength. Accordingly, hereafter the terms “light” and “radiation” are used synonymously, i.e. a light source may also be referred to as a radiation
15 source, a light distribution may also be referred to as a radiation distribution and so on. With the projection optical unit, the reticle is imaged onto a light-sensitive material, which is for example applied to a wafer or some other substrate, in particular of a semiconductor material. In this way, the light-sensitive material is exposed in a structured manner to a pattern predefined by the reticle. Since the reticle has tiny structural elements, which are intended to
20 be transferred to the substrate with high precision, it is required that the illumination optical unit generates a desired light distribution precisely and reproducibly and the imaging by the projection optical unit takes place precisely and reproducibly.

In addition to further optical elements, the illumination optical unit and the projection optical
25 unit may have in the light path at least one mirror, which deflects the light in a predefined way by reflection at its optical surface. How the light deflection specifically takes place depends on the formation of the optical surface, in particular on its form. The optical surface may for example be formed as a metallic layer or as a series of layers with alternating refractive indices. Irrespective of the formation of the optical surface, it is impossible to achieve a
30 perfect reflection, and so part of the light is always absorbed and causes a heating up of the mirror. The heating up is in turn accompanied by a thermal expansion and, as a consequence, a deformation of the mirror and in particular of the optical surface, and this may ultimately cause the optical properties of the mirror to change.

In order to minimize as much as possible the effects of the heating up of the mirror on its optical properties, the mirror may be produced from a material with an extremely low coefficient of thermal expansion. Such materials may have a zero crossing temperature, in the direct vicinity of which the thermal expansion is particularly low and ideally even zero. When
5 using such materials, it is therefore generally endeavored to operate the mirror at its zero crossing temperature or in the direct vicinity of its zero crossing temperature. This in turn has the effect that the zero crossing temperature should correspond as exactly as possible to the temperature that the mirror assumes under the intended operating conditions or should lie somewhat above this temperature. A zero crossing temperature somewhat above the expected
10 operating temperature of the mirror has the advantage that instances of local heating up of the mirror due to maxima of the light intensity only lead to very little expansion of the mirror.

It is known from US10427974B2 to influence the coefficient of thermal expansion and its increase with respect to the temperature of doped quartz glass by means of a heat treatment.

15 It may be advantageous or even necessary to form the mirror from more than one part, for example if the mirror is intended to have cooling channels or if the mirror is intended to be larger than the material blanks available for the production of the mirror.

20 A multipart mirror with cooling channels is known from DE 102020208648.6, which is not a prior publication.

A problem with mirrors that are formed from more than one part is that of connecting the individual parts of the mirror in such a way that meets the high requirements for lithographic
25 optical parts.

The invention is based on the object of forming a multipart mirror of a microlithographic projection exposure apparatus in such a way that it meets very high optical requirements and has great dimensional stability under the intended operating conditions. In particular, the
30 mirror is intended to undergo very little thermally induced deformation under the intended operating conditions.

This object is achieved by the combination of features of claim 1.

In the case of the method according to the invention for producing a mirror of a microlithographic projection exposure apparatus, a first mirror part and a second mirror part are provided, which are in contact in the region of a first connecting surface of the first mirror part and a second connecting surface of the second mirror part. For forming a durable
5 connection between the first mirror part and the second mirror part, the first mirror part and the second mirror part are heated up to a holding temperature of at least 400°C and are kept at the holding temperature during a holding time. After the holding time has elapsed, the first mirror part and the second mirror part are cooled down to a first cooling temperature at a first cooling rate of a maximum of 100 K/h.

10

The method according to the invention has the advantage that it allows a very durable connection to be formed between the mirror parts. The process of forming this connection is also referred to hereafter as bonding. A further advantage of the method according to the invention is that the multipart mirror produced by it of a microlithographic projection
15 exposure apparatus meets very high optical requirements and can be formed in such a way that it has great dimensional stability under the intended operating conditions. In particular, the mirror may be formed in such a way that it undergoes very little thermally induced deformation under the intended operating conditions. This can be achieved by the mirror being formed with a zero crossing temperature that is averaged over a relevant volume and
20 deviates very little from a predefined value and/or being formed with a zero crossing temperature that has only little spatial variation within this relevant volume, and is consequently very homogeneous. Particularly relevant here are regions of the volume of the mirror that are arranged at such a small distance from its optical surface that they can make it deform to an inadmissible extent.

25

An important finding of the invention is that the heat treatment used for connecting the mirror parts can have an influence on the zero crossing temperature of the mirror that should be taken into account when devising the heat treatment, in order to make it possible to produce particularly high-quality mirrors. In other words, the zero crossing temperature of the material
30 from which the mirror parts are produced and which has been set with extremely great effort to a desired value can be changed by the bonding. For this reason, within the method according to the invention, for example a relatively low cooling rate is chosen, and so it is possible to precisely monitor the heat treatment process at any time and as far as possible in the entire volume of the mirror parts.

A low cooling rate has the advantage for example that, when there is a variation of the cooling rate, the temperature differences in different regions of the volume of the mirror parts are comparatively small. This in turn has the consequence of comparatively little inhomogeneities of the zero crossing temperature of the mirror. A further advantage is that temperature errors of the oven in which the mirror parts are kept at a temperature or of the mirror parts themselves do not have such a strong effect on the homogeneity of the zero crossing temperature. A low cooling rate generally has a greater effect on the absolute value of the zero crossing temperature than a great cooling rate. However, this can already be taken into account in the production of the material for the mirror parts.

The heat treatment may be carried out in air or in an inert gas atmosphere. It is similarly also possible to carry out the heat treatment under vacuum conditions.

The first mirror part and the second mirror part may be provided in the form of an intermediate product that is produced by wringing the first connecting surface of the first mirror part and the second connecting surface of the second mirror part. This makes it easier to carry out the heat treatment, since the mirror parts do not have to be handled individually and there is no need for the effort of correctly positioning the mirror parts in relation to one another during the heat treatment. Furthermore, there are good chances of the bonding being successful if the wringing has previously succeeded, because the connecting surfaces of the mirror parts must be brought very close together during bonding and the connecting surfaces have to meet similar preconditions for the bonding as for the wringing. Furthermore, there is the possibility of investigating the intermediate product for possible defects before the heat treatment. The defects may be for example inclusions between the connecting surfaces. If defects are discovered, the intermediate product may be rejected or subjected to some other treatment. As a result, it can be avoided that the elaborate heat treatment is carried out with a defective intermediate product.

During the wringing, the first mirror part and the second mirror part may be brought together in such a way that first a partial region of the first connecting surface and a partial region of the second connecting surface come into contact and form a common contact surface and the contact surface is increased in size by continuing to bring the first mirror part and the second mirror part together in a rolling direction.

The transitional zone between the common contact surface, within which the second mirror part has already been wrung onto the first mirror part, and the non-wrung region of the first and second connecting surfaces is also referred to as the wringing front. Continuing to bring
5 together the first mirror part and the second mirror part together has the effect that the wringing front advances in a monitored manner in the rolling direction. This successive wringing has the advantage that the relative alignment of the two mirror parts in relation to one another can be monitored very exactly during the entire wringing operation and undesired spontaneous wringing can be avoided. Furthermore, at any time in the wringing operation
10 there is a fluidic connection between the region of the wringing front and the surrounding area, and so an escape of gas from this region is ensured at any time and gas inclusions between the connecting surfaces can be largely prevented.

The first mirror part and the second part may be brought together in such a way that contact
15 with the first mirror part first occurs in a region of the second surface that adjoins the outer contour of the second mirror part. It is similarly also possible to bring the first mirror part and the second mirror part together in such a way that contact with the first mirror part first occurs in the region of the center of the second connecting surface. This allows the way in which the wringing operation is carried out to be made to suit the respective circumstances, in particular
20 the formation of the second mirror part.

On a side of the second mirror part that is facing away from the second connecting surface, a region for formation of an optical surface may be provided.

25 The first connecting surface of the first mirror part and/or the second connecting surface of the second mirror part may have a curvature. A curved first connecting surface and/or second connecting surface is of advantage in particular when it is envisaged to form a curved optical surface on the second mirror part, because then for example a constant thickness is possible, and therefore a uniform deformability of the second mirror part. Furthermore, a constant
30 distance between the cooling channels and the optical surface can then be created with little effort. The curvature of the first connecting surface and/or the second connecting surface may correspond to the curvature of the intended optical surface of the mirror.

There is also the possibility that the first mirror part has a first connecting surface which is formed in a planar manner or has a large average radius of curvature, in particular an average radius of curvature of more than 10 m, along at least one direction. Then a thin second mirror part can be used, in particular a second mirror part with a thickness of 0.5 mm to 10 mm, which has a second connecting surface formed in a planar manner. If the second mirror part has cooling channels, the thickness is determined from the bottom of the cooling channels. Such a thin second mirror part has the advantage that its second connecting surface can be deformed and, as a result, adapted to the form of the first connecting surface of the first mirror part. This means that there is no need for the effort of producing a second mirror part with a curved second connecting surface.

With respect to a wavelength λ of 633 nm, the form of the first connecting surface of the first mirror part and/or the second connecting surface of the second mirror part may deviate from a predefined form by less than $\lambda/2$, preferably less than $\lambda/10$. The first connecting surface of the first mirror part and/or the second connecting surface of the second mirror part may have a roughness of less than 5 nm, preferably less than 1 nm. The term “roughness” in this case subsumes the randomly distributed deviations from a smooth surface. Precisely formed and smoothed connecting surfaces make wringing and bonding easier, reduce the risk of gas inclusions and increase the load-bearing capacity of the connection. Before the wringing or bonding, one of the two connecting surfaces may be adapted to the actual form of the other of the two connecting surfaces. In this way, the precision can be increased still further.

There is the possibility that the curvature of the first connecting surface is formed convexly and the curvature of the second connecting surface is formed concavely or the curvature of the first connecting surface is formed concavely and the curvature of the second connecting surface is formed convexly and, while the first mirror part and the second mirror part are being brought together, the convex curvature has an average radius of curvature of which the absolute amount is less than the absolute amount of the average radius of curvature of the concave curvature. This has the advantage that a locally sequential wringing can be ensured, because the distance between the two connecting surfaces increases with increasing distance from the wringing front. The risk of undesired wringing at a distance from the wringing front is reduced. Furthermore, the risk of gas inclusions is reduced.

Before being heated up to the holding temperature, the intermediate product may be stored for a storage time of at least 2 hours, preferably at least 12 hours, particularly preferably at least 24 hours, at a storage temperature which is at least 80°C and at most 400°C. Preferably, the storage temperature is at least 160°C, particularly preferably at least 250°C. Furthermore, the storage temperature is preferably at most 350°C. Storage at these temperatures has the advantage that excess moisture diffuses out from the region of the connecting surfaces of the mirror parts and the strength increases. In particular, an anhydrous material is conducive to the formation of covalent bonds during the subsequent heat treatment at the holding temperature. If comparatively low values in the range from for example 400°C to 550°C are chosen for the holding temperature, the storage takes place for a long period of time at low storage temperatures, for example one to two weeks at a holding temperature of a maximum of 250°C.

The first mirror part and the second mirror part are in particular heated up to a holding temperature of at least 500°C, preferably at least 600°C, particularly preferably at least 700°C. With the aid of a high holding temperature, a particularly durable connection of the mirror parts can be achieved, because then a particularly high number of covalent bonds are formed.

The first mirror part and the second mirror part may be heated up to a holding temperature of a maximum of 900°C. In addition to the advantage mentioned, high holding temperatures are also accompanied by the disadvantage that the influence of the heat treatment on the zero crossing temperature increases. With the maximum value mentioned for the holding temperature, a good compromise can be achieved.

The first mirror part and the second mirror part may be heated up to the holding temperature at a heating rate of a maximum of 150 K/h, preferably a maximum of 100 K/h. Slow heating up has the advantage that fewer stresses form between inner and outer regions of the mirror parts and more time is available for the outward diffusion of water.

The holding time may be at least 8 hours, preferably at least 12 hours, particularly preferably at least 20 hours. A long holding time has the advantage that the connection between the

mirror parts has a greater tensile strength, because more covalent bonds are formed. To make efficient production possible, the holding time is preferably a maximum of 72 hours, particularly preferably a maximum of 48 hours.

- 5 The first cooling temperature may be 700°C or less. In particular, the first cooling temperature may be 600°C or less. The first cooling rate is preferably 50 K/h or less. In particular, the first cooling rate is between 1 K/h and 20 K/h. Lower cooling rates have the advantage that the first mirror part and the second mirror part cool down relatively uniformly over the entire volume. High spatial temperature gradients are avoided and the variations in temperature over
10 time are similar in the entire volume. This in turn leads to a relatively homogeneous distribution of the zero crossing temperature in the mirror.

- After the cooling at the first cooling rate to the first cooling temperature, the first mirror part and the second mirror part may be cooled at a second cooling rate, which is greater than the
15 first cooling rate, to a second cooling temperature, which is less than the first cooling temperature. The second cooling temperature may be 500°C or less, preferably 400°C or less. The second cooling rate may be 150 K/h or less. In particular, the second cooling rate lies between 5 K/h and 100 K/h. After the cooling to the second cooling temperature, the first mirror part and the second mirror part may be cooled down further in the direction of room
20 temperature. The further cooling may take place at a third cooling rate, which at least initially has a greater value than the second cooling rate. The use of greater cooling rates at low cooling temperatures allows the heat treatment to be speeded up considerably without appreciable losses in quality of the mirror, since with low cooling temperatures the influence of the cooling profile on the zero crossing temperature of the mirror is significantly lower than
25 with high cooling temperatures.

- The first mirror part and the second mirror part may be cooled in such a way that a sliding average value of the cooling rate, formed over a temperature interval of 20 K, has an identical relative variation over time in a temperature range from 900°C to 700°C, except for a
30 deviation of a maximum of 2 K/h, in the entire volume of the first mirror part and/or the second mirror part. This means that the cooling can take place in such a way that, after allowing for a respective potentially existing time difference, the variations over time of this sliding average value at all locations of the first mirror part and/or the second mirror part differ by a maximum of 2 K/h. Preferably, the deviation of the sliding average value in the

temperature range from 900°C to 700°C is a maximum of 1 K/h. Furthermore, it may be provided that the deviation of the sliding average value in the temperature range from 700°C to 500°C is a maximum of 4 K/h, preferably a maximum of 2 K/h. With the aid of this specification, a consistently high quality of the mirrors produced can be achieved. In this case, the heat treatment can in turn be speeded up without any great adverse effects by the somewhat greater tolerance at low temperatures. Furthermore, the first mirror part and the second mirror part may be cooled in such a way that an inhomogeneity of the zero crossing temperature of the mirror attributable to the heat treatment is a maximum of +/- 1 K, preferably a maximum of +/- 0.5 K. These tolerances should be maintained in particular within a volume zone of the mirror that overlaps laterally with its optical surface and extends in depth from the optical surface to the cooling channels, i.e. from the optical surface to the beginning of the cooling channels. It is similarly also possible that these tolerances are maintained within a volume zone of the mirror that overlaps laterally with its optical surface and extends in depth from the optical surface to 1 cm below the cooling channels.

The first cooling rate and/or the second cooling rate may be chosen dependent on the material composition of the first mirror part and/or the second mirror part. In particular, the first cooling rate and/or the second cooling rate are chosen dependent on the OH content and/or on the titanium content of the first mirror part and/or the second mirror part. Since the influence of heat treatment on the zero crossing temperature of the mirror depends on the material composition of the mirror parts, the achievable precision with respect to the properties of the mirror, in particular with respect to its zero crossing temperature, can be improved by taking the material composition into account when devising the heat treatment.

The first cooling rate and/or the second cooling rate may be chosen dependent on a desired average zero crossing temperature of the mirror. This makes it possible to produce mirrors with a very small deviation of the average zero crossing temperature from a predefined value. In particular, the first cooling rate and/or the second cooling rate may be chosen dependent on a desired average zero crossing temperature within a volume zone of the mirror that overlaps laterally with its optical surface and extends in depth from the optical surface to the cooling channels or to 1 cm below the cooling channels.

For determining the first cooling rate and/or the second cooling rate, a material sample of the material from which the first mirror part and/or the second mirror part has been produced may

be analyzed. It may be provided in particular that the material sample undergoes all of the heat treatments of the material of the first mirror part and/or the second mirror part in an identical way. In this way, it is possible for the first cooling rate and/or the second cooling rate to be adjusted very precisely to suit the material composition of the first mirror part
5 and/or the second mirror part without any risk of damage to the mirror parts, and so very high precision and low variance with respect to the average zero crossing temperature of the mirrors produced can be achieved.

The invention also relates to a mirror of a microlithographic projection exposure apparatus,
10 which has a first mirror part, a second mirror part and an optical surface for the reflection of light. The first mirror part and the second mirror part are durably connected to one another in the region of a first connecting surface of the first mirror part and a second connecting surface of the second mirror part by a heat treatment. The mirror has within a volume zone that overlaps laterally with the optical surface and extends in depth from the optical surface to 1
15 cm an average zero crossing temperature that deviates from a predefined value by a maximum of ± 1 K. In this volume zone, the predefined value may decrease with increasing distance from the optical surface.

Such a precise average zero crossing temperature can be achieved in spite of the influence of
20 the heat treatment on the zero crossing temperature by the first mirror part and the second mirror part being connected to one another with the aid of the method according to the invention. Preferably, the average zero crossing temperature deviates from the predefined value by a maximum of ± 0.5 K, particularly preferably by a maximum of ± 0.2 K.

25 Ignoring the influence on the zero crossing temperature of the mirror of the heat treatment with the aid of which the mirror parts are connected to one another, which is taken into account in the method according to the invention, it is scarcely possible to achieve such high accuracies.

30 The first connecting surface of the first mirror part and/or the second connecting surface of the second mirror part may have a curvature. There is in this case the possibility that the curvature of the first connecting surface of the first mirror part is not formed rotationally symmetrically, and so it has different average radii of curvature, and/or the curvature of the

second connecting surface of the second mirror part is not formed rotationally symmetrically, and so it has different average radii of curvature.

Cooling channels may be formed in the first mirror part and/or in the second mirror part. In this case, the mirror may have within a volume zone that overlaps laterally with its optical surface and extends in depth from the optical surface to the cooling channels, i.e. from the optical surface to the beginning of the cooling channels, an average zero crossing temperature that deviates from a predefined value by a maximum of ± 1 K, preferably a maximum of ± 0.5 K, particularly preferably by a maximum of ± 0.2 K. If the mirror has cooling channels, this condition may take the place of the previously mentioned condition, which independently of any cooling channels relates to a volume zone from the optical surface to a depth of 1 cm, and so the volume zone in the case of a mirror with cooling channels can extend to a depth of less than 1 cm. It is similarly also possible that the mirror has within a volume zone that overlaps laterally with its optical surface and extends in depth from the optical surface to 1 cm below the cooling channels an average zero crossing temperature that deviates from a predefined value by a maximum of ± 1 K, preferably a maximum of ± 0.5 K, particularly preferably by a maximum of ± 0.2 K. In the volume zones mentioned, the predefined value may in each case decrease with increasing distance from the optical surface. The cooling channels may be formed as open toward the first connecting surface of the first mirror part and/or toward the second connecting surface of the second mirror part.

The cooling channels may be arranged in each case with the greatest part of their longitudinal extent laterally within the region intended for the optical surface. This makes possible efficient cooling of the region that has a particularly great influence on a temperature-induced deformation of the optical surface.

Furthermore, the cooling channels may run parallel to the optical surface. This makes particularly uniform cooling of the optical surface possible. In particular, the cooling channels may reach up to the optical surface to within a distance of 1 to 6 mm. The form deviation between the second connecting surface of the second mirror part and the optical surface may be a maximum of 3 mm, preferably no more than 20 μm .

In a refinement, the clear distance between adjacent cooling channels is no more than 15 mm, preferably no more than 5 mm. Small distances between the cooling channels make efficient

and uniform cooling possible and can facilitate the deformability of the second mirror part during the wringing, in particular in the case of a rolling direction transverse to the cooling channels of the second mirror part. In particular, the values for the width of the cooling channels, for the clear distance between adjacent cooling channels and for the distance
5 between the cooling channels and the optical surface may be approximately the same.

The transverse dimensions of the cooling channels may be 0.2 to 10 mm. The depth of the cooling channels, i.e. the transverse dimension approximately perpendicular to the first connecting surface of the first mirror part or to the second connecting surface of the second
10 mirror part, may be greater than the width of the cooling channels, i.e. the transverse dimension perpendicular to the depth. In particular, the depth of the cooling channels may be more than twice the width of the cooling channels. As a result, with the same flow cross section, there is a smaller risk of a deformation of the optical surface of the mirror due to the pressure of the fluid in the cooling channels, because the proportion of the surface area of the
15 cavities formed by the cooling channels parallel to the optical surface area is smaller than in the case of wide cooling channels that have a small depth.

The first mirror part may have a greater thickness than the second mirror part. This makes efficient cooling of the optical surface possible, and at the same time a great mechanical
20 stability of the mirror.

The invention also relates to an illumination optical unit with a mirror formed according to the invention and/or produced by the method according to the invention.

25 The invention also relates to a projection optical unit with a mirror formed according to the invention and/or produced by the method according to the invention.

Finally, the invention relates to a microlithographic projection exposure apparatus with an illumination optical unit according to the invention and/or a projection optical unit according
30 the invention.

The invention is explained in more detail below on the basis of the exemplary embodiments that are represented in the drawing,
in which:

Fig. 1 schematically shows an exemplary embodiment of a projection exposure apparatus for EUV projection lithography in a meridional section,

5 Fig. 2 shows an exemplary embodiment of a projection exposure apparatus for DUV projection lithography in a schematic representation,

Fig. 3 shows an exemplary element of a mirror that has been produced by the method according to the invention in a schematic sectional representation,

10

Fig. 4 shows the first exemplary embodiment of the mirror, represented in Fig. 3, in a further schematic sectional representation,

Fig. 5 shows a flow diagram for explaining the procedure according to the invention when
15 connecting the lower part and the upper part and

Fig. 6 shows a snapshot during the wringing of the upper part onto the lower part in a schematic sectional representation.

20 Figure 1 schematically shows an exemplary embodiment of a projection exposure apparatus 1 for EUV projection lithography in a meridional section.

In the following text, the essential component parts of a microlithographic projection exposure apparatus 1 are first described by way of example with reference to Fig. 1. The
25 description of the basic construction of the projection exposure apparatus 1 and its components should not understood here as limiting.

One embodiment of an illumination system 2 of the projection exposure apparatus 1 has, in addition to a light or radiation source 3, an illumination optical unit 4 for illuminating an
30 object field 5 in an object plane 6. In an alternative embodiment, the radiation source 3 may also be provided as a separate module from the remaining illumination system. In this case, the illumination system does not comprise the radiation source 3.

A reticle 7 arranged in the object field 5 is exposed. The reticle 7 is held by a reticle holder 8. The reticle holder 8 is displaceable by way of a reticle displacement drive 9, in particular in a scanning direction.

- 5 For purposes of explanation, a Cartesian xyz-coordinate system is shown in Fig. 1. The x-direction runs perpendicularly into the plane of the drawing. The y-direction runs horizontally and the z-direction runs vertically. The scanning direction runs along the y-direction in Fig. 1. The z-direction runs perpendicularly to the object plane 6.
- 10 The projection exposure apparatus 1 comprises a projection optical unit 10. The projection optical unit 10 serves for imaging the object field 5 into an image field 11 in an image plane 12. The image plane 12 runs parallel to the object plane 6. Alternatively, an angle between the object plane 6 and the image plane 12 that differs from 0° is also possible.
- 15 It is shown that a structure on the reticle 7 is imaged onto a light-sensitive layer of a wafer 13 arranged in the region of the image field 11 in the image plane 12 or some other substrate. The wafer 13 is held by a wafer holder 14. The wafer holder 14 is displaceable by way of a wafer displacement drive 15, in particular along the y-direction. The displacement on the one hand of the reticle 7 by way of the reticle displacement drive 9 and on the other hand of the
- 20 wafer 13 by way of the wafer displacement drive 15 can take place in such a way as to be synchronized with one another.

The radiation source 3 is an EUV radiation source. The radiation source 3 emits an illumination radiation 16, which is also referred to below as used radiation or illumination

25 light. In the exemplary embodiment shown, the illumination radiation 16 has a wavelength in the EUV range, in particular in the range between 5 nm and 30 nm. The radiation source 3 may be a plasma source, for example an LPP source (Laser Produced Plasma) or a GDPP source (Gas Discharge Produced Plasma). It may also be a synchrotron-based radiation source. Similarly, the radiation source 3 may be a free electron laser (FEL).

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The illumination radiation 16 emerging from the radiation source 3 is focused by a collector 17. The collector 17 may be a collector with one or more ellipsoidal and/or hyperboloidal reflection surfaces. The illumination radiation 16 may be incident on the at least one reflection surface of the collector 17 with grazing incidence (GI), i.e. at angles of incidence of greater

than 45°, or with normal incidence (NI), i.e. at angles of incidence of less than 45°. The collector 17 may be structured and/or coated, on the one hand for optimizing its reflectivity for the illumination radiation 16 and on the other hand for suppressing extraneous light.

5 Downstream of the collector 17, the illumination radiation 16 propagates through an intermediate focus in an intermediate focal plane 18. The intermediate focal plane 18 may represent a separation between a radiation source module, having the radiation source 3 and the collector 17, and the illumination optical unit 4.

10 The illumination optical unit 4 comprises a deflection mirror 19 and, arranged downstream thereof in the beam path, a first facet mirror 20. The deflection mirror 19 may be a plane deflection mirror or, alternatively, a mirror with a beam-influencing effect that goes beyond a purely deflecting effect. Alternatively or in addition, the deflection mirror 19 may be embodied as a spectral filter which separates a used light wavelength of the illumination
15 radiation 16 from extraneous light with a wavelength deviating therefrom. If the first facet mirror 20 is arranged in a plane of the illumination optical unit 4 that is optically conjugate to the object plane 6 as a field plane, it is also referred to as a field facet mirror. The first facet mirror 20 comprises a multiplicity of individual first facets 21, which are also referred to below as field facets. Only some of these facets 21 are shown in Fig. 1 by way of example.

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The first facets 21 may be embodied as macroscopic facets, in particular as rectangular facets or as facets with an arcuate peripheral contour or a peripheral contour of part of a circle. The first facets 21 may be embodied as plane facets or alternatively as convexly or concavely curved facets.

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As known for example from DE 10 2008 009 600 A1, the first facets 21 themselves may also be composed in each case of a multiplicity of individual mirrors, in particular a multiplicity of micromirrors. The first facet mirror 20 may in particular be formed as a microelectromechanical system (MEMS system). For details, reference is made to

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DE 10 2008 009 600 A1.

Between the collector 17 and the deflection mirror 19, the illumination radiation 16 travels horizontally, i.e. along the y-direction.

In the beam path of the illumination optical unit 4, a second facet mirror 22 is arranged downstream of the first facet mirror 20. If the second facet mirror 22 is arranged in a pupil plane of the illumination optical unit 4, it is also referred to as a pupil facet mirror. The second facet mirror 22 may also be arranged at a distance from a pupil plane of the illumination optical unit 4. In this case, the combination of the first facet mirror 20 and the second facet mirror 22 is also referred to as a specular reflector. Specular reflectors are known from US 2006/0132747 A1, EP 1 614 008 B1 and US 6,573,978.

The second facet mirror 22 comprises a plurality of second facets 23. In the case of a pupil facet mirror, the second facets 23 are also referred to as pupil facets.

The second facets 23 may likewise be macroscopic facets, which may for example have a round, rectangular or else hexagonal periphery, or alternatively be facets made up of micromirrors. In this regard, reference is likewise made to DE 10 2008 009 600 A1.

The second facets 23 may have planar or alternatively convexly or concavely curved reflection surfaces.

The illumination optical unit 4 consequently forms a twice-faceted system. This basic principle is also referred to as a honeycomb condenser (fly's eye integrator).

It may be advantageous to arrange the second facet mirror 22 not exactly in a plane that is optically conjugate to a pupil plane of the projection optical unit 10. In particular, the second pupil facet mirror 22 may be arranged so as to be tilted in relation to a pupil plane of the projection optical unit 10, as is described for example in DE 10 2017 220 586 A1.

With the aid of the second facet mirror 22, the individual first facets 21 are imaged into the object field 5. The second facet mirror 22 is the last beam-shaping mirror or else, in fact, the last mirror for the illumination radiation 16 in the beam path before the object field 5.

In a further embodiment of the illumination optical unit 4 that is not shown, a transmission optical unit contributing in particular to the imaging of the first facets 21 into the object field 5 may be arranged in the beam path between the second facet mirror 22 and the object field 5. The transmission optical unit may have exactly one mirror or else alternatively two or more

mirrors, which are arranged one behind the other in the beam path of the illumination optical unit 4. The transmission optical unit may in particular comprise one or two normal-incidence mirrors (NI mirrors) and/or one or two grazing-incidence mirrors (GI mirrors).

- 5 In the embodiment shown in Fig. 1, the illumination optical unit 4 has exactly three mirrors downstream of the collector 17, specifically the deflection mirror 19, the field facet mirror 20 and the second facet mirror 22.

10 In a further embodiment of the illumination optical unit 4, there is also no need for the deflection mirror 19, and so the illumination optical unit 4 can then have exactly two mirrors downstream of the collector 17, specifically the first facet mirror 20 and the second facet mirror 22.

15 The imaging of the first facets 21 into the object plane 6 by means of the second facets 23 or using the second facets 23 and a transmission optical unit is often only approximate imaging.

The projection optical unit 10 comprises a plurality of mirrors M_i , which are consecutively numbered in accordance with their arrangement in the beam path of the projection exposure apparatus 1.

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In the example shown in Fig. 1, the projection optical unit 10 comprises six mirrors M_1 to M_6 . Alternatives with four, eight, ten, twelve or any other number of mirrors M_i are similarly possible. The projection optical unit 10 is a twice-obscured optical unit. The last-but-one mirror M_5 and the last mirror M_6 have in each case a through-opening, through which, during
25 the exposure of the wafer 13, the radiation contributing to the exposure passes on its way from the reticle 7 to the wafer 13. The projection optical unit 10 has an image-side numerical aperture that is greater than 0.5 and may also be greater than 0.6, and may be for example 0.7 or 0.75.

- 30 The reflection surfaces of the mirrors M_i may be embodied as freeform surfaces without an axis of rotational symmetry. Alternatively, the reflection surfaces of the mirrors M_i may be designed as aspherical surfaces with exactly one axis of rotational symmetry of the reflection surface form. Just like the mirrors of the illumination optical unit 4, the mirrors M_i may have

highly reflective coatings for the illumination radiation 16. These coatings may be designed as multilayer coatings, in particular with alternating layers of molybdenum and silicon.

5 The projection optical unit 10 has a large object-image offset in the y-direction between a y-coordinate of a center of the object field 5 and a y-coordinate of the center of the image field 11. This object-image offset in the y-direction may be approximately the same size as a z-distance between the object plane 6 and the image plane 12.

10 In particular, the projection optical unit 10 may have an anamorphic form. In particular, it has different imaging scales β_x , β_y in the x- and y-directions. The two imaging scales β_x , β_y of the projection optical unit 10 are preferably at $(\beta_x, \beta_y) = (+/- 0.25, +/- 0.125)$. A positive imaging scale β means imaging without an image reversal. A negative sign for the imaging scale β means imaging with an image reversal.

15 The projection optical unit 10 consequently leads to a reduction in size with a ratio of 4:1 in the x-direction, i.e. in a direction perpendicular to the scanning direction.

The projection optical unit 10 leads to a reduction in size of 8:1 in the y-direction, i.e. in the scanning direction.

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Other imaging scales are similarly possible. Imaging scales with the same sign and the same absolute value in the x-direction and y-direction are also possible, for example with absolute values of 0.125 or of 0.25.

25 The number of intermediate image planes in the x-direction and in the y-direction in the beam path between the object field 5 and the image field 11 may be the same or, depending on the embodiment of the projection optical unit 10, may differ. Examples of projection optical units 10 with different numbers of such intermediate images in the x-direction and y-direction are known from US 2018/0074303 A1.

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In each case one of the second facets 23 is assigned to exactly one of the first facets 21 for respectively forming an illumination channel for illuminating the object field 5. This may in particular produce illumination according to the Köhler principle. The far field is decomposed into a multiplicity of object fields 5 with the aid of the first facets 21. The first facets 21

produce a plurality of images of the intermediate focus on the second facets 23 respectively assigned to them.

By way of an assigned second facet 23, the first facets 21 are in each case imaged onto the
5 reticle 7 in a manner superposed on one another for the purposes of illuminating the object field 5. The illumination of the object field 5 is in particular as homogeneous as possible. It preferably has a uniformity error of less than 2%. The field uniformity can be achieved by way of the superposition of different illumination channels.

10 The illumination of the entrance pupil of the projection optical unit 10 can be defined geometrically by an arrangement of the second facets 23. The intensity distribution in the entrance pupil of the projection optical unit 10 can be set by selecting the illumination channels, in particular the subset of the second facets 23, which guide light. This intensity distribution is also referred to as illumination setting or illumination pupil filling.

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A likewise preferred pupil uniformity in the region of defined illuminated sections of an illumination pupil of the illumination optical unit 4 can be achieved by a redistribution of the illumination channels.

20 Further aspects and details of the illumination of the object field 5 and in particular of the entrance pupil of the projection optical unit 10 are described below.

In particular, the projection optical unit 10 may have a homocentric entrance pupil. The latter may be accessible. It may also be inaccessible.

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The entrance pupil of the projection optical unit 10 often cannot be exactly illuminated with the second facet mirror 22. When imaging the projection optical unit 10, which images the center of the second facet mirror 22 telecentrically onto the wafer 13, the aperture rays often do not intersect at a single point. However, it is possible to find an area in which the distance
30 of the aperture rays determined in pairs becomes minimal. This area represents the entrance pupil or an area in real space that is conjugate thereto. In particular, this area has a finite curvature.

It may be that the projection optical unit 10 has different positions of the entrance pupil for the tangential beam path and for the sagittal beam path. In this case, an imaging element, in particular an optical component of the transmission optical unit, should be provided between the second facet mirror 22 and the reticle 7. With the aid of this optical element, the different
5 position of the tangential entrance pupil and the sagittal entrance pupil can be taken into account.

In the arrangement of the components of the illumination optical unit 4 shown in Fig. 1, the second facet mirror 22 is arranged in an area conjugate to the entrance pupil of the projection
10 optical unit 10. The first facet mirror 20 is arranged so as to be tilted in relation to the object plane 6. The first facet mirror 20 is arranged so as to be tilted in relation to an arrangement plane defined by the deflection mirror 19.

The first facet mirror 20 is arranged so as to be tilted in relation to an arrangement plane
15 defined by the second facet mirror 22.

Fig. 2 shows an exemplary embodiment of a projection exposure apparatus 1 for DUV projection lithography in a schematic representation. DUV stands here for “Deep Ultraviolet”. In particular, the projection exposure apparatus 1 may be designed for operation at a
20 wavelength of 193 nm.

The projection exposure apparatus 1 has an illumination optical unit 4 and a projection optical unit 10. The internal structure of the illumination optical unit 4 and the internal structure of the projection optical unit 10, which may in each case comprise for example optical
25 components, sensors, manipulators etc., are not shown in detail. In the case of the projection optical unit 10, a mirror M is indicated as representative of its optical components. The mirror M may be cooled with the aid of a cooling medium, which is provided by a cooling device 24. The cooling medium is a fluid, for example water. In addition or alternatively, the illumination optical unit 4 may have a cooled mirror M and an associated cooling device 24.
30 The projection optical unit 10 and/or the illumination optical unit 4 may also have a number of cooled mirrors M and cooling devices 24. In the case of the illumination optical unit 4 and in the case of the projection optical unit 10, lenses and further mirrors - cooled or uncooled - may for example be present as further optical components.

By analogy, at least one cooling device 24, which may for example be connected to the mirror M3, may also be provided in the exemplary embodiment of the projection exposure apparatus 1 shown in Fig. 1.

- 5 The radiation required for the operation of the projection exposure apparatus 1 is generated by a radiation source 3. The radiation source 3 may be in particular an excimer laser, for example an argon fluoride laser, which generates illumination radiation 16 of the wavelength 193 nm.

10 Arranged between the illumination optical unit 4 and the projection optical unit 10 is a reticle holder 8, fixed on which is a reticle 7, also referred to as a mask. The reticle holder 8 has a reticle displacement drive 9. Arranged downstream of the projection optical unit 10, seen in the direction of radiation, is a wafer holder 14, which carries a wafer 13 or some other substrate and has a wafer displacement drive 15.

- 15 Also shown furthermore in Fig. 2 is a control device 25, which is connected to the illumination optical unit 4, the projection optical unit 10, the cooling device 24, the radiation source 3, the reticle holder 8 or the reticle displacement drive 9 and the wafer holder 14 or the wafer displacement drive 15. By analogy, the projection exposure apparatus of Fig. 1 may likewise have a control device 25, which may be connected to corresponding components.

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The projection exposure apparatus 1 serves the purpose of imaging the reticle 7 onto the wafer 13 with high precision. For this purpose, the reticle 7 is illuminated with the aid of the illumination optical unit 4 and the illuminated reticle 7 is imaged onto the wafer 13 with the aid of the projection optical unit 10. Specifically, the following procedure is adopted:

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- The illumination optical unit 4 transforms the illumination radiation 16 generated by the radiation source 3 in an exactly defined way by means of its optical components and guides it onto the reticle 7. Depending on the embodiment, the illumination optical unit 4 may be formed in such a way that it illuminates the entire reticle 7 or only a partial region of the
30 reticle 7. The illumination optical unit 4 is capable of illuminating the reticle 7 in such a way that there are almost identical illumination conditions at each illuminated point of the reticle 7. In particular, the intensity and the angular distribution of the incident illumination radiation 16 are almost identical for each illuminated point of the reticle 7.

The illumination optical unit 4 is capable of illuminating the reticle 7 optionally with illumination radiation 16 of a multiplicity of different angular distributions. These angular distributions of the illumination radiation 16 are also referred to as illumination settings. The desired illumination setting is generally selected in dependence on the structural elements
5 formed on the reticle 7. Used relatively often for example are dipole or quadrupole illumination settings, in the case of which the illumination radiation 16 is incident on each illuminated point of the reticle 7 from two different directions or from four different directions, respectively. Depending on the form of the illumination optical unit 4, the different illumination settings may be produced for example by means of different diffractive optical
10 elements in combination with a zoom axicon optical unit or by means of mirror arrays, which have in each case a multiplicity of small mirrors that are arranged next to one another and are individually adjustable with respect to their angular position.

The reticle 7 may be formed for example as a glass plate, which is transparent to the
15 illumination radiation 16 supplied by the illumination optical unit 4 and applied to which are opaque structures, for example in the form of a chromium coating.

The projection exposure apparatus 1 may be formed in such a way that the entire reticle 7 is illuminated at the same time by the illumination optical unit 4 and is imaged completely onto
20 the wafer 13 by the projection optical unit 10 in a single exposure step.

Alternatively, the projection exposure apparatus 1 may also be formed in such a way that only a partial region of the reticle 7 is illuminated at the same time by the illumination optical unit 4 and the reticle displacement drive 9 is activated by the control device 25 in such a way that,
25 during the exposure of the wafer 13, the reticle 7 is moved in relation to the illumination optical unit 4 and, as a result, the illuminated partial region migrates over the reticle 7 as a whole. The wafer 13 is moved synchronously by a suitably adjusted activation of the wafer displacement drive 15, in which the imaging properties of the projection optical unit 10 are also taken into account, and so the respectively illuminated partial region of the reticle 7 is
30 imaged onto a partial region of the wafer 13 provided for it. This movement of the reticle 7 and the wafer 13 is also referred to as scanning.

In order to be able to transfer the latent image produced by the exposure of the wafer 13 in both embodiments of the projection exposure apparatus 1 into a physical structure, a light-

sensitive layer is applied to the wafer 13. The image of the reticle 7 is formed in this light-sensitive layer by exposure and a permanent structure can be produced from it on the wafer 13 with the aid of subsequent chemical processes.

- 5 The reticle 7 is generally imaged onto the wafer 13 not only once, but multiple times next to one another. For this purpose, after each imaging of the reticle 7 onto the wafer 13, the wafer holder 14 is displaced laterally in a way corresponding to the size of the image of the reticle 7 on the wafer 13. The imaging of the reticle 7 may be performed here in each case as a whole or sequentially by scanning. The chemical treatment of the wafer 13 is only started when the
10 desired number of imagings of the reticle 7 onto the wafer 13 have been carried out.

Fig. 3 shows an exemplary embodiment of a mirror 26 that has been produced by the method according to the invention in a schematic sectional representation. Fig. 4 shows the same exemplary embodiment of the mirror 26 in a further schematic sectional representation, in
15 which the section is taken along a sectional line A-A depicted in Fig. 3. To be able to represent as many details of the mirror 26 as possible, the sectional line A-A has a lateral offset as it passes through the mirror 26. In Fig. 3, the section is taken along the sectional line B-B shown in Fig. 4. In Fig. 3 and 4, the representation of the mirror 26 and its component parts is not to scale and is highly abstract, in order to present the invention as clearly as
20 possible. This also applies to all of the other figures.

In the case of one of the projection exposure apparatuses 1 shown in Fig. 1 and 2, the mirror 26 can be used and has a lower part 27 and an upper part 28, which are in each case produced from quartz glass, Ti-doped quartz glass or a glass ceramic. The terms “lower part” and
25 “upper part” have been chosen because the lower part 27 is generally formed much thicker than the upper part 28, and consequently as it were carries the upper part 28. The terms do not however have anything to do with the orientation of the mirror 26 in relation to the direction of gravitational force in the fitted state of the mirror 26. During the operation of the projection exposure apparatus 1, the upper part 28 may be arranged above or below or alongside the
30 lower part 27 with respect to the direction of gravitational force, or assume some other relative position with respect to it. The lower part 27 is also referred to as the first mirror part 27 and the upper part 28 is also referred to as the second mirror part 28.

The lower part 27 and the upper part 28 are rigidly connected to one another in the region of a connecting surface 29 of the lower part 27 and a connecting surface 30 of the upper part 28 by means of the method according to the invention described in more detail below. In the exemplary embodiment shown, the connecting surface 29 of the lower part 27 is formed in a concavely curved manner. The curvature may be formed spherically, aspherically or according to a freeform surface. The connecting surface 30 of the upper part 28 is curved in a way complementary to the connecting surface 29 of the lower part 27, and accordingly has a convex curvature, which may be formed spherically, aspherically or according to a freeform surface. Consequently, the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 can engage with one another in close contact. As an alternative to a curved formation, the connecting surface 29 of the lower part 27 and the connecting surface 30 of the upper part 28 may also be formed in a planar manner.

On the side that is facing away from its connecting surface 29 and is shown at the bottom in Fig. 3, the lower part 27 is formed in a planar manner. On the side that is facing away from its connecting surface 30 and is shown at the top in Fig. 3, the upper part 28 is formed in a concavely curved manner and has a reflective optical surface 31 with an identical curvature. The curvature may be formed as spherical, aspherical or according to a freeform surface and in particular correspond to the curvature of the connecting surface 30 of the upper part 28. Even when the connecting surfaces 29 and 30, the surface of the upper part 28 facing away from the connecting surface 30 and the optical surface 31 are formed in each case in a rotationally symmetrical manner, they respectively have in the sectional areas of Fig. 3 and 4 a slightly different curvature, since these sectional areas are formed at different distances from the centers of the surfaces mentioned. However, the differences in distance in comparison with the absolute values of the radii of curvature are in each case very small, and so different curvatures are not perceptible in the representations of Fig. 3 and 4.

As an alternative to this, it is also possible that the optical surface 31 is formed in a planar manner. This is the case in particular whenever the connecting surface 29 of the lower part 27 and the connecting surface 30 of the upper part 28 are formed in a planar manner.

The optical surface 31 is embodied as a coating applied to the upper part 28. The formation of the coating depends on at which wavelength the optical surface 31 is intended to produce its reflective effect. In the case of a desired reflection in the DUV range, i.e. in the case of the

mirror M of Fig. 2, the coating may be formed as an aluminum layer. If, on the other hand, a reflection in the EUV range is intended, as in the case for example of the mirror M3 of Fig. 1, the coating may be formed in particular from alternately successive layers of silicon and molybdenum and possibly one or more further layers of a different composition and serving for example as protective layers.

The upper part 28 also has a number of elongate cooling channels 32, which run parallel to one another and to the optical surface 31 and extend laterally in the region of the optical surface 31 and possibly somewhat beyond it. Accordingly, the cooling channels 32 in the case of the exemplary embodiment shown are formed in a curved manner. The cooling channels 32 reach up to the optical surface 31 to within a distance of about 1 to 6 mm and are formed as open toward the connecting surface 30 of the upper part 28. Accordingly, the cooling channels 32 have elongate cooling channel openings 33 in the region of the connecting surface 30 of the upper part 28. The transverse dimensions of the cooling channel 32 may be about 0.2 to 10 mm, the depth of the cooling channels 32, i.e. the dimension approximately perpendicular to the connecting surface 30 of the upper part 28, generally being considerably greater than the width, i.e. the dimension approximately parallel to the connecting surface 30 of the upper part 28. For example, the depth of the cooling channel 32 may be more than twice the width of the cooling channels 32. The clear distance between adjacent cooling channels 32 is generally no more than 15 mm, preferably no more than 5 mm. The values for the width of the cooling channels 32, for the clear distance between adjacent cooling channels 32 and for the distance between the cooling channels 32 and the optical surface 31 may be approximately the same.

In the case of a formation of the connecting surface 30 of the upper part 28 that is not rotationally symmetrical, it may have different average radii of curvature for different azimuth angles or, to put it another way, with respect to different directions. In this case, the region of the connecting surface 30 of the upper part 28 within which the absolute amount of the average radius of curvature has the greatest value may run in a direction transverse, in particular perpendicular, to the longitudinal extents of the cooling channel openings 33. Mutually adjacent regions of the connecting surface 29 of the lower part 27 and the connecting surface 30 of the upper part 28 may in the unconnected state have slightly different average radii of curvature, the average radius of curvature of the region of the

convexly formed surface generally having a smaller absolute value than the average radius of curvature of the corresponding region of the concavely formed surface.

The lower part 27 has a number of distributor channels 34 and collector channels 35, which
5 extend from the connecting surface 29 of the lower part 27 in the direction of the side of the lower part 27 facing away from the connecting surface 29 into the lower part 27. Inside the lower part 27, the distributor channels 34 open out into a fluid distributor 36 and the collector channels 35 open out into a fluid collector 37. The distributor channels 34 and the collector channels 35 widen in each case in a step-shaped manner toward the connecting surface 29 of
10 the lower part 27 and respectively overlap there with the opposite ends of two cooling channel openings 33. In other words, one distributor channel 34 respectively overlaps with one end of two cooling channel openings 33 and one collector channel 35 respectively overlaps with the two other ends of the same two cooling channel openings 33. Accordingly, one distributor channel 34 is fluidically connected at its one end to the fluid distributor 36 and at its other end
15 to two cooling channels 32. By analogy, one collector channel 35 is fluidically connected at its one end to the fluid collector 37 and at its other end to two cooling channels 32.

It is consequently possible to supply a fluid, for example water, to the cooling channels 32 through the fluid distributor 36 and to the distributor channels 34, each distributor channel 34
20 respectively supplying two cooling channels 32 and the fluid distributor 36 supplying all of the distributor channels 34 with fluid. The fluid flows through the cooling channel 32 and then flows on via the collector channels 35 into the fluid collector 37, via which it can be removed. In this case, the fluid of every two cooling channels 32 flows respectively into one collector channel 35 and the fluid of all the collector channels 35 flows into the fluid collector
25 37. The supply of the fluid to the fluid distributor 36 and the removal of the fluid from the fluid collector 37 can take place with the aid of the cooling device 24, which for this purpose can be connected to the fluid distributor 36 and the fluid collector 37.

Adjusting the temperature of the supplied fluid to a temperature below the temperature of the
30 upper part 28 can achieve the effect that the fluid extracts heat from the upper part 28 as it flows through the cooling channel 32. This extraction of heat is intended in particular to compensate for the input of heat due to the radiation that is incident on the optical surface 31 during the operation of the lithographic system. Since the optical surface 31 does not completely reflect the incident radiation, part of the radiation is absorbed by the optical

surface 31 and, depending on the formation of the optical surface 31, also absorbed by the upper part 28 and converted into heat. Since the optical surface 31 and the upper part 28 have a certain thermal conductivity, part of this heat is directed to the cooling channels 32 and can be taken up there by the fluid and transported away. In this way, the rise in temperature of the mirror 26 caused by the radiation can be limited and the deformation of the optical surface 31 caused by effects of thermal expansion can be reduced in comparison with an uncooled mirror 26. As a consequence, the imaging errors caused by the deformation are also reduced.

The formation and arrangement of the cooling channels 32, the distributor channels 34, the collector channels 35, the fluid distributor 36 and the fluid collector 37 may also be modified in various ways. For example, the cooling channels 32 may be arranged in the lower part 27 and be formed as open toward the connecting surface 29 of the lower part 27, and so the cooling channels 32 have elongate cooling channel openings 33 in the region of the connecting surface 29 of the lower part 27. There may also be no need for the distributor channels 34 and the collector channels 35, and the fluid distributor 36 and the fluid collector 37 may be connected directly to the cooling channels 32 etc.

For producing the mirror 26, the lower part 27 and the upper part 28 are produced as separate parts and then connected to one another. The optical surface 31 is generally only formed after connecting the lower part 27 and the 28, in order to achieve the highest possible precision, in particular with respect to its form, and to avoid damage to the optical surface 31 during the connecting process. A material with a very low coefficient of thermal expansion is used for the production of the lower part 27 and the upper part 28. Suitable materials are for example quartz glass, quartz glass doped with titanium oxide or special glass ceramics. The lower part 27 and the upper part 28 may be cut out from a common material blank. However, there is also the possibility of using different material blanks for the lower part 27 and the upper part 28 if they do not differ too much from one another with respect to their material parameters.

For example, a quartz glass mixed with titanium oxide, which has a zero crossing temperature averaged over the volume of the lower part 27 of between 22 and 25°C, may be used for the production of the lower part 27. The zero crossing temperature has been adjusted here to match the expected temperature of the lower part 27, taking into account the cooling of the mirror 26, during the operation of the lithographic system. Depending on the method for producing the material used for the lower part 27, the increase in the coefficient of thermal

expansion at 22°C is preferably less than about 1.35 ppb/K². At least within a region which overlaps laterally with the optical surface 31 in the finished mirror 26, the zero crossing temperature has a homogeneity of better than +/- 5 K, the homogeneity being better in the region of the connecting surface 29 of the lower part 27 than on the side facing away from it.

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The lower part 27 is cut out from the material blank and then worked by grinding and polishing. The connecting surface 29 of the lower part 27 here may in particular be brought into a form that corresponds approximately to the intended form of the optical surface 31, which is formed at a later time on the upper part 28. The form deviation between the

10 connecting surface 29 of the lower part 27 and the optical surface 31 is a maximum of 3 mm, preferably no more than 200 µm. If the connecting surface 29 of the lower part 27 has a circular peripheral border, its diameter is generally between 20 and 100 cm with a sagitta of up to 3% of the diameter. A spherical basic form of the connecting surface 29 of the lower part 27 may be overlaid with any desired function, and so a freeform surface can be obtained.

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With respect to a wavelength λ of 633 nm used for the measurement, the polishing of the connecting surface 29 of the lower part 27 may take place with a deviation from a predefined form (figure) of less than $\lambda/2$, preferably less than $\lambda/10$. Furthermore, a roughness of less than 5 nm, preferably less than 1 nm, may be achieved in this case. The term “roughness” in this

20 case subsumes the randomly distributed deviations from a smooth surface. Form or figure deviations are considered to comprise both longwave deviations from the predefined form and shortwave, and more point-like, not randomly distributed deviations. The longwave form deviation may also turn out to be somewhat greater than the aforementioned values of $\lambda/2$ and $\lambda/10$. With respect to the shortwave deviation, the values mentioned are however maintained

25 wherever possible. For example, deviations with spatial frequencies of several cm do not have such a disruptive effect. Deviations with spatial frequencies below 100 µm generally much more disruptive.

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In order to avoid drying in of remains of grinding and polishing agents, the lower part 27 is rinsed off directly after the grinding and polishing. Furthermore, mechanical wet cleaning may be carried out. The surface of the lower part 27 may be additionally cleaned with solvents, organic and inorganic cleaning agents or by means of a plasma treatment etc.

When working the lower part 27, it must be ensured that damage at depth is avoided, because small amounts of water, other process agents such as for example polishing agents or contaminants, can be left behind in micro cracks and they may evaporate away and lead to local blistering when the lower part 27 is heated up. To avoid or eliminate possible damage at depth, dry and/or wet etching steps or other suitable optical working steps may be used. Furthermore, graduated grinding steps may be used, or contactless removal performed, for example by etching with oxygen plasma, which may be followed by a polishing step. Freedom from damage at depth is demonstrated for example by briefly etching with fluoric acid this not leading to local etch pits. A fluoric acid bath is suitable at the same time as a cleaning step for removing hydrocarbons.

After the grinding and polishing or lapping, if applicable the distributor channels 34 and the collector channels 35 as well as the fluid distributor 36 and the fluid collector 37 are formed in the lower part 27. Depending on the formation of the lower part 27, the cooling channels 32 may also be formed in the lower part 27. The distributor channels 34 and the collector channels 35 as well as the fluid distributor 36 and the fluid collector 37 generally have transverse dimensions, i.e. dimensions transverse to the direction of flow of the fluid, that are much greater than the corresponding dimensions of the cooling channels 32.

The respective channels may be formed by milling, grinding, drilling, laser ablation, ultrasound ablation or etching or a combination of these methods. As a last method step, etching with fluoric acid may be provided in each case, in order to avoid later crack propagation and to form a surface in the channels that is only slightly roughened in a way conducive to flow.

In order to protect the already worked, in particular polished, surface of the lower part 27 from breakouts at the edges, for example at the peripheries of the cooling channel openings 33, and from similar damage, a protective resist may be applied to the surface of the lower part 27 before the forming of the channels. Any breakouts at the edges that occur in spite of this precautionary measure may be smoothed out locally or eliminated by a bevel running for example around the cooling channel openings 33. However, this bevel is disadvantageous in terms of flow and in terms of strength because of the notch effect, and should be avoided as far as possible.

As an alternative to the procedure described above, there is the possibility of first forming the channels in the lower part 27 and only then working the surface of the lower part 27 by grinding, lapping and/or polishing. This however results in a certain rounding at the edges of the cooling channel openings 33 or other openings, because for example the polishing disks
5 have a finite stiffness and bulge into the cooling channel openings 33 or other openings. This rounding at the edges can be counteracted by inserting or cementing in placeholders of the same material as the lower part 27 into the cooling channel openings 33 or other openings. The placeholders are ground away and polished together with the connecting surface 29 of the lower part 27 and reduce the widths of the gaps caused by the cooling channel openings 33 or
10 other openings. The gaps remaining between the placeholders and the surrounding material of the lower part 27 may also be grouted with a glass-or ceramic-powder-filled putty, and so during the polishing there is at most slight bulging, and accordingly very little rounding at the edges. Alternatively, local reworking may take place by means of robot polishing or ion beam polishing in order to minimize the rounding at the edges. After the working of the surface of
15 the lower part 27, the placeholders, and if applicable the grouting material, are removed again.

In order to avoid, or at least reduce, rounding at the edges, ablating or etching methods may be used as an alternative to mechanical surface working. If, within these methods, a resist mask is applied to the regions that are not to be worked, underetching may occur in the
20 peripheral regions of the resist mask. The adverse effects of this underetching can be counteracted by suitable mechanical, laser-ablative or etching reworking.

A material with identical or similar properties as described for the lower part 27 may be used for the production of the upper part 28. The material properties of the upper part 28 may only
25 deviate within predefined limits from the material properties of the lower part 27. For example, a very different thermal expansion behavior of the lower part 27 and the upper part 28 would be problematic because the lower part 27 and 28 are rigidly connected to one another.

30 After the cutting out of the upper part 28 from the material blank, the surface of the upper part 28, in particular the connecting surface 30, may be worked in an analogous way to that described for the lower part 27, and analogous requirements with respect to form deviation and roughness have to be met. The requirements with respect to the form deviation can be relaxed somewhat if the upper part 28 is comparatively thin.

Depending on the variant of the embodiment, the upper part 28 may have cooling channels 32 and/or other channels, such as for example distributor channels 34 and collector channels 35. All of these channels can be produced in an analogous way to that described for the lower part 27 and analogous measures can be used for reducing the rounding at the edges etc.

The upper part 28 generally has a thickness of between 10 and 40 mm, but under certain preconditions may also have a smaller thickness. Depending on the thickness, it may be necessary to cement or wring the upper part 28 onto a glass substrate as a carrier material for working, in order to achieve a stiffness sufficient for precise working.

Tools that have the same or very similar nominal curvature as the tools for working the connecting surface 29 of the lower part 27 may be used for the working of the connecting surface 30 of the upper part 28 by grinding, lapping and/or polishing. Optionally, a further step may be provided after that, in which the actual forms of the connecting surface 29 of the lower part 27 and the connecting surface 30 of the upper part 28 are measured and the connecting surface 30 of the upper part 28 is locally adapted to the connecting surface 29 of the lower part 27 by robot polishing, plasma etching, ion beam ablation or compacting high-energy irradiation.

20

In the case of embodiments of the mirror 26 in which the connecting surface 29 of the lower part 27 is substantially planar or has a very small curvature, and so the absolute value of the average radius of curvature for at least one azimuth angle is greater than 10 m, there is the possibility of using a comparatively thin upper part 28, which has a thickness of 0.5 to 10 mm, and of forming the connecting surface 30 of the upper part 28 in a planar manner. In this case, the upper part 28 may be deformed as it is being connected to the lower part 27, and as a result the connecting surface 30 of the upper part 28 may be adapted to the form of the connecting surface 29 of the lower part 27. For the working required before the connection, the upper part 28 may be cemented onto a sufficiently rigid carrier material or wrung onto the carrier material

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As an alternative to the use of an upper part 28 cut out from a material blank, a thin upper part 28 of titanium-doped quartz glass may also be produced by flowing out, for example on molten metal (float glass), pouring over a long break-away edge, pressing and sintering of

glass soot or indirectly by way of a gray body. These methods have the advantage that the upper part 28 is produced from a sheet a few millimeters thick, in which good homogeneity with respect to the material parameters can be achieved, and that it may be possible to dispense with mechanical working. To be able to achieve similar thermal expansion behavior as in the case of the lower part 27 with an upper part 28 from such a sheet, the OH content of the sheet should deviate by a maximum of 5% and the titanium content of the sheet should deviate by a maximum of 0.05% from the respective content of the lower part 27. In the case of very thin sheets from which upper parts 28 with thicknesses of less than 2 mm are produced, these requirements can also be relaxed somewhat.

10

When the lower part 27 and the upper part 28 have been finished, they can be connected to one another in the region of their connecting surfaces 29, 30. The connection is performed in two steps: In a first step, the upper part 28 is wrung onto the lower part 27, i.e. is brought up so close to the lower part 27 that it becomes attached to the lower part 27 as a result of the Van-der-Waals forces between the atoms of the lower part 27 and the atoms of the upper part 28. With this first step, which may take place at room temperature, an intermediate product comprising the lower part 27 and the upper part 28 is produced. In a second step, the connection between the upper part 28 and the lower part 27 is strengthened by means of a bonding process, by which covalent bonds are formed between the atoms of the lower part 27 and the atoms of the upper part 28, and so the upper part 28 and the lower part 27 are durably connected very strongly to one another. The procedure according to the invention within the bonding process and the preparations taken for this are explained in more detail below.

15
20

Fig. 5 shows a flow diagram explaining the procedure according to the invention when connecting the lower part 27 and the upper part 28. The lower part 27 and the upper part 28 may be produced in the way described above in processes that proceed approximately in parallel or completely independently of one another in processes that are separate in terms of space and/or time.

25

To make it possible to form a durable connection, in a step S1 the lower part 27 and the upper part 28 are cleaned, activated and dried, in particular in the region of their connecting surfaces 29, 30. For example, the connecting surface 29 of the lower part 27 and the connecting surface 30 of the upper part 28 may be simultaneously cleaned, ablated and activated by

30

etching, for example with fluoric acid, by sputtering or by plasma treatment, in particular with hydrogen or oxygen plasma.

Step S1 is followed by step S2, in which the upper part 28 is wrung onto the lower part 27.

5 For wringing onto the lower part 27, the connecting surface 30 of the upper part 28 is brought up so close to the connecting surface 29 of the lower part 27 that a strong attraction occurs as a result of the Van-der-Waals forces between the atoms near the surface of the upper part 28 and the atoms near the surface of the lower part 27 and ultimately connects the upper part 28 and the lower part 27 to one another. Since the Van-der-Waals forces only act over very short
10 distances, it is necessary to bring the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 very close together. This is only possible within a relatively large surface area if the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 are very smooth, have almost exactly the same form and are largely free from contaminants. It is also of great importance for bringing the
15 connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 sufficiently close together to prevent as far as possible inclusions of air or other gases between the connecting surfaces 30, 29. These gas inclusions may also have adverse effects during the later use of the mirror 28. A possible procedure for the wringing is shown in Fig. 6.

Fig. 6 shows a snapshot during the wringing of the upper part 28 onto the lower part 27 in a
20 schematic sectional representation, the section being taken along a sectional line C-C shown in Fig. 4, and consequently perpendicular to the longitudinal extents of the cooling channels 32.

In the case of the exemplary embodiment shown, the connecting surface 29 of the lower part
25 27 and the connecting surface 30 of the upper part 28 have at least approximately complementary curvatures. As can be seen from Fig. 6, the connecting surface 30 of the upper part 28 is not brought up to the connecting surface 29 of the lower part 27 in parallel alignment over the full surface area, but instead the connecting surfaces 29, 30 form an angle with one another when they are brought together and initially only meet one another in the
30 region of their peripheral surfaces shown on the left in Fig. 6. In Fig. 6, the angle is exaggerated in order that the effect can be seen. As they are brought together, initially there is only contact between the upper part 28 and the lower part 27 in a small region of the connecting surfaces 29, 30, and so initially only a comparatively small contact surface 38 is formed between the upper part 28 and the lower part 27. Van-der-Waals forces produce their

attractive effect within the contact surface 38, and so wringing of the connecting surface 30 of the upper part 28 onto the connecting surface 29 of the lower part 27 occurs in the region of the contact surface 38.

5 The upper part 28 is then successively pivoted further toward the lower part 27 and thereby brought ever closer to it, and so the contact surface 38 increases in size. Accordingly, the surface area within which the upper part 28 is wrung onto the lower part 27 also increases in size. The linearly formed transition between the wrung region of the connecting surfaces 29, 30 and the non-wrung region of the connecting surfaces 29, 30 is referred to hereafter as the
10 wringing front. In the representation of Fig. 6, the wringing front runs perpendicularly in relation to the plane of the drawing and approximately parallel to the longitudinal extents of the cooling channels 32. This applies at least in the region where the wringing front passes through the plane of the drawing. The wringing front may be formed as a straight line or slightly curved and, as the upper part 28 is increasingly brought up to the lower part 27,
15 moves from the left to the right, i.e. the approach of the upper part 28 to the lower part 27 progresses successively from the left to the right. The progressive approach is also referred to hereafter as “rolling”, and so in the representation of Fig. 6 the upper part 28 is rolled up to the lower part 27 from the left to the right. The direction of the rolling movement is illustrated in Fig. 6 by an arrow and is referred to hereafter as the rolling direction 39.

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The successive wringing with a steadily migrating, linear wringing front has the effect that the gas is successively displaced out of the intermediate space between the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27, and as a result the risk of gas inclusions is reduced considerably. The wringing operation is ended when the
25 connecting surface 30 of the upper part 28 has been wrung onto the connecting surface 29 of the lower part 27 over the full surface area.

In the case of exemplary embodiments in which the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 are not formed in a rotationally
30 symmetrical manner, the connecting surface 30 of the upper part 28 is preferably rolled up to the connecting surface 29 of the lower part 27 parallel to a direction in which the connecting surfaces 29, 30 have the smallest absolute value of the average radius of curvature.

The escape of the gas from the intermediate space between the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 can be made even easier to some extent by the connecting surface 30 of the upper part 28 and the connecting surface 29 of the lower part 27 not having exactly the same curvature.

5

As can be seen from Fig. 6, the rolling direction 39 runs transversely, in particular perpendicularly, to the longitudinal extent of the cooling channel openings 33 and the cooling channels 32. Since the thickness of the upper part 28 is reduced considerably in the region of the cooling channels 32, these regions act in a way similar to joints and make it easier for the upper part 28 to bend in these regions. This has the consequence that only a comparatively small force is required to keep the upper part 28 outside the contact surface 38 temporarily at a sufficiently great distance from the lower part 27 to prevent wringing from occurring there and to make the connecting surface 30 of the upper part 28 continuously approach the connecting surface 29 of the lower part 27. Furthermore, in the region of the contact surface 38, better engagement of the connecting surface 30 of the upper part 28 in close contact with the connecting surface 29 of the lower part 27 is achieved and very reliable wringing is made possible as a result.

It is similarly also possible to bring the upper part 28 up to the lower part 27 in such a way that the rolling direction 39 runs parallel to the longitudinal extent of the cooling channel openings 33 and the cooling channel 32. In the case of this embodiment, particularly reliable venting of the intermediate space between the upper part 28 and the lower part 27 is ensured because the gas can escape along the cooling channel openings 33. The deformability in the rolling direction is reduced to some extent in comparison with the embodiment described above.

The wringing of the upper part onto the lower part in step S2 has the effect of producing an intermediate product comprising the lower part 27 and the upper part 28, which are rigidly connected to one another in the region of their connecting surfaces 29, 30. The intermediate product has to meet various quality requirements and only when it satisfies these quality requirements is it passed on to the heat treatment described in more detail below. Otherwise, the intermediate product is re-worked or rejected. The quality requirements relate for example to the occurrence of inclusions between the connecting surfaces 29 and 30.

In a step S3, which follows step S2, the intermediate product is stored for a storage time at a storage temperature. The storage time may be for example 24 hours. The storage temperature lies above room temperature and may be for example between 80°C or preferably 160°C and 400°C. In particular, the storage temperature may be between 250°C and 350°C. Heating ramps are also possible in combination with storage at a constant storage temperature. The storage at elevated temperature has the effect that excess moisture diffuses out from the region of the connecting surfaces 29, 30, in particular via the cooling channel openings 33. Depending on the pre-treatment of the lower part 27 and the upper part 28 before the wringing and the time period between production and further use of the intermediate product, there may also be no need for step S3, in particular when there are small clear distances between adjacent cooling channels 32.

Step S3 is followed by a step S4, in which a heat treatment for the forming of a very durable connection between the lower part 27 and the upper part 28 is started. The formation of the connection by the heat treatment is also referred to hereafter as bonding. In step S4, the intermediate product is brought into a bonding oven, which guarantees for example a temperature homogeneity of better than 2 K. An atmosphere of air or an inert gas may be provided in the bonding oven. It is similarly also possible to evacuate the bonding oven and to carry out the heat treatment under vacuum conditions. In the bonding oven, the intermediate product is heated up at a heating rate to a holding temperature. The heating rate has values below 150 K/h, preferably below 100 K/h. The holding temperature lies in the range from 400°C to 900°C, temperatures above 500°C, particularly above 600°C and most particularly above 700°C being preferred.

This is next followed by a step S5, according to which the intermediate product is kept at the holding temperature for a holding time. The holding time may be at least 8 hours, in particular at least 12 hours or at least 20 hours.

Step S5 is followed by a step S6, in which the intermediate product is cooled, and so its temperature is reduced from the holding temperature. The cooling may take place in particular in a number of stages, the temperature of the intermediate product being reduced at different cooling rates. For example, the reduction of the temperature of the intermediate product may

first take place at a cooling rate below 100 K/h or below 50 K/h, in particular between 1 K/h and 20 K/h, until a temperature of 700°C or 600°C is reached. Below 700°C or 600°C, the reduction of the temperature may take place more quickly, for example at a cooling rate below 150 K/h, in particular in the range from 5 K/h to 100 K/h or from 20 K/h to 100 K/h.

- 5 When a temperature of for example 500°C or 400°C is reached, the limitation of the cooling rate may be abandoned completely, and the cooling can then take place at any cooling rate until room temperature is reached. The cooling may for example be provided in each case by the temperature of the gas that surrounds the intermediate product and/or the temperature otherwise of the surrounding area being lowered to a value below the temperature of the
- 10 intermediate product. Step S6 completes the flow diagram.

- When setting the parameters of the heat treatment, in particular the holding temperature and the cooling rates, it should be remembered that they can have an influence on the zero crossing temperature and the increase in the coefficient of thermal expansion of the mirror 26
- 15 produced with them. Although these material properties are generally already set to desired values during the production of the material used for the lower part 27 and the upper part 28, they can be changed again by the heat treatment. If, therefore, a low tolerance with respect to the zero crossing temperature and the increase in the coefficient of thermal expansion of the mirror 26 is required, it is not enough just to use a material that meets these requirements for
- 20 production. It is additionally necessary for the heat treatment of the intermediate product to be precisely planned, while allowing for potential influencing of the parameters mentioned.

- When doing so, it should be remembered that the influence of the heat treatment on the zero crossing temperature and the increase in the coefficient of thermal expansion depends on the material composition of the intermediate product, in particular on its OH and titanium content.
- 25 To achieve low tolerances, the OH and titanium content should therefore be taken into account. If this is not known with sufficient accuracy, it may be provided within the method according to the invention to carry out measurements for determining the OH content and the titanium content. Furthermore, measurements for determining the actual zero crossing temperature and the actual increase in the coefficient of thermal expansion of the intermediate
- 30 product may be carried out before the heat treatment. Since some of these measurements are not nondestructive, they are not carried out on the intermediate product itself, but on an accompanying test piece, i.e. on a piece of the material from which the intermediate product has been produced. The accompanying test piece is subjected to the same heat treatment as the intermediate product and, if the lower part 27 and the upper part 28 already undergo a heat

treatment before the formation of the intermediate product, this is also carried out on the accompanying test piece. If the lower part 27 and the upper part 28 have been produced from different blanks, an accompanying test piece may be respectively provided for the lower part 27 and for the upper part 28.

5

Then a heat treatment profile, i.e. an intended variation over time of the temperature of the intermediate product, is individually determined from the known or measured material properties for each intermediate product or for each group of intermediate products with very similar material properties. Particularly important here is the cooling profile, in particular the cooling rates used.

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In this way, a mirror 26 of which the average zero crossing temperature has a maximum deviation of ± 1 K from a desired zero crossing temperature can be produced. Maximum deviations of ± 0.5 K or even ± 0.2 K are also possible. These values relate in each case to a zero crossing temperature that is averaged over a volume zone of the mirror 26 that overlaps laterally with the optical surface 31 and extends in depth from the optical surface 31 to 1 cm. It is similarly also possible that this volume zone extends in depth from the optical surface 31 to the cooling channels 32 or to 1 cm below the cooling channels 32. In the representation of Fig. 3, an extent to the cooling channels 32 means an extent to the upper edges of the cooling channels 32 and an extent to 1 cm below the cooling channels 32 means an extent to 1 cm below the lower edges of the cooling channels 32. In this volume zone, the predefined value may in each case decrease with increasing distance from the optical surface 31.

15

20

A further difficulty in the heat treatment is that of ensuring that the entire volume of the intermediate product is treated according to the intended heat treatment profile. For example, the peripheral regions of the intermediate product react much quicker to cooling acting from the outside, and accordingly cool down much quicker than the core regions. This problem is alleviated somewhat to the extent that it is not necessary to achieve approximately the same temperatures in the entire volume of the intermediate product at every point in time of the cooling. It is true that the predefined cooling profile, i.e. the time-dependent decrease in temperature, should be maintained as exactly as possible at each location of the intermediate product. However, a time difference between the individual locations is admissible.

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Accordingly, the cooling is controlled in such a way that the cooling profiles are in each case locally maintained and for this purpose the cooling rates are adapted step by step during the

cooling, if appropriate a number of times and over a number of hours, in order to achieve this objective. The adaptations may for example extend over a time of one to six hours.

- In particular, it should be ensured that a sliding average value of the cooling rate, formed over
5 a temperature interval of 20 K, has an identical relative variation over time in a temperature
range from 900°C to 700°C, except for a deviation of a maximum of 2 K/h, in the entire
volume of the intermediate product. This means that the cooling should take place in such a
way that, after allowing for a respective potentially existing time difference, the variations
over time of this sliding average value at all locations of the intermediate product differ by a
10 maximum of 2 K/h. Preferably, the deviation of the sliding average value in the temperature
range from 900°C to 700°C is a maximum of 1 K/h. Furthermore, it may be provided that the
deviation of the sliding average value in the temperature range from 700°C to 500°C is a
maximum of 4 K/h, preferably a maximum of 2 K/h. With these measures it should ultimately
be achieved that an inhomogeneity of the zero crossing temperature attributable to the heat
15 treatment within a volume zone of the mirror 26 that overlaps laterally with the optical surface
31 and extends in depth from the optical surface 31 to 1 cm is a maximum of +/- 1 K,
preferably a maximum of +/- 0.5 K. It is similarly also possible that this volume zone extends
to the cooling channels 32 or to 1 cm below the cooling channels 32.
- 20 The heat treatment is intended to achieve a tensile strength of the connection of the lower part
27 and the upper part 28 of 50 MPa or more.

In a modification, the lower part 27 and the upper part 28 are pressed against one another
during the heat treatment.

25

The bonding process described above is in the same way also possible without wringing. The
procedure is in that case analogously identical, with the individual steps then having to be
carried out not with the intermediate product but with the lower part 27 and the upper part 28,
which are not connected to one another by wringing.

30

Following the bonding process, the upper part 28 may be worked away to a thickness above
the cooling channels 32 of 2 to 10 mm.

After the working step of the thickness reduction of the upper part 28, or instead of this working step, the upper part 28 is re-worked in such a way that on its side which is facing away from the connecting surface 30, and on which the optical surface 31 is to be formed, it has a predefined form with high precision and satisfies predefined roughness criteria. Then,
5 the optical surface 31 is formed there. This may take place for example by applying an aluminum layer or alternately applying layers of molybdenum and silicon.

Reference signs

5	1	Projection exposure apparatus
	2	Illumination system
	3	Radiation source
	4	Illumination optical unit
	5	Object field
10	6	Object plane
	7	Reticle
	8	Reticle holder
	9	Reticle displacement drive
	10	Projection optical unit
15	11	Image field
	12	Image plane
	13	Wafer
	14	Wafer holder
	15	Wafer displacement drive
20	16	Illumination radiation
	17	Collector
	18	Intermediate focal plane
	19	Deflection mirror
	20	First facet mirror
25	21	First facet
	22	Second facet mirror
	23	Second facet
	24	Cooling device
	25	Control device
30	26	Mirror
	27	Lower part
	28	Upper part
	29	Connecting surface
	30	Connecting surface

- 31 Optical surface
32 Cooling channel
33 Cooling channel opening
34 Distributor channels
5 35 Collector channels
36 Fluid distributor
37 Fluid collector
38 Contact surface
39 Rolling direction
10

- M Mirror
M1 Mirror
15 M2 Mirror
M3 Mirror
M4 Mirror
M5 Mirror
M6 Mirror

Patent claims

1. A method for producing a mirror (26) of a microlithographic projection exposure
5 apparatus (1), wherein
 - a first mirror part (27) and a second mirror part (28) are provided, which are in contact in the region of a first connecting surface (29) of the first mirror part (27) and a second connecting surface (30) of the second mirror part (28),
 - for forming a durable connection between the first mirror part (27) and the second
10 mirror part (28), the first mirror part (27) and the second mirror part (28) are heated up to a holding temperature of at least 400°C and are kept at the holding temperature during a holding time,
 - after the holding time has elapsed, the first mirror part (27) and the second mirror part (28) are cooled down to a first cooling temperature at a first cooling rate of a maximum
15 of 100 K/h.
2. The method as claimed in claim 1, wherein the first mirror part (27) and the second mirror part (28) are provided in the form of an intermediate product that is produced by wringing the first connecting surface (29) of the first mirror part (27) and the second
20 connecting surface (30) of the second mirror part (28).
3. The method as claimed in one of the preceding claims, wherein, before being heated up to the holding temperature, the intermediate product is stored for a storage time of at least 2 hours at a storage temperature which is at least 80°C and at most 400°C.
25
4. The method as claimed in one of the preceding claims, wherein the first mirror part (27) and the second mirror part (29) are heated up to a holding temperature of a maximum of 900°C.
30
5. The method as claimed in one of the preceding claims, wherein the first mirror part (27) and the second mirror part (28) are heated up to the holding temperature at heating rate of a maximum of 150 K/h.
- 35 6. The method as claimed in one of the preceding claims, wherein the holding time is at least 8 hours.

7. The method as claimed in one of the preceding claims, wherein the first cooling temperature is 700 °C or less.
- 5 8. The method as claimed in one of the preceding claims, wherein, after the cooling at the first cooling rate to the first cooling temperature, the first mirror part (27) and the second mirror part (28) are cooled at a second cooling rate, which is greater than the first cooling rate, to a second cooling temperature, which is less than the first cooling temperature.
- 10 9. The method as claimed in one of the preceding claims, wherein the first mirror part (27) and the second mirror part (28) are cooled in such a way that a sliding average value of the cooling rate, formed over a temperature interval of 20 K, has an identical relative variation over time in a temperature range from 900°C to 700°C, except for a deviation of a maximum of 2 K/h, in the entire volume of the first mirror part (27) and/or the
15 second mirror part (28).
10. The method as claimed in one of the preceding claims, wherein the first cooling rate and/or the second cooling rate are/is chosen dependent on the material composition of the first mirror part (27) and/or the second mirror part (28).
20
11. The method as claimed in one of the preceding claims, wherein the first cooling rate and/or the second cooling rate are/is chosen dependent on a desired average zero crossing temperature of the mirror (26).
- 25 12. The method as claimed in one of the preceding claims, wherein, for determining the first cooling rate and/or the second cooling rate, a material sample of the material from which the first mirror part (27) and/or the second mirror part (28) have/has been produced is analyzed.
- 30 13. A mirror of a microlithographic projection exposure apparatus (1), with
 - a first mirror part (27),
 - a second mirror part (28),
 - an optical surface (31) for the reflection of light,wherein
35
 - the first mirror part (27) and the second mirror part (28) are durably connected to one another in the region of a first connecting surface (29) of the first mirror part (27) and a

second connecting surface (30) of the second mirror part (28) by a heat treatment and
- the mirror (26) has within a volume zone that overlaps laterally with the optical surface
(31) and extends in depth from the optical surface (31) to 1 cm an average zero crossing
temperature that deviates from a predefined value by a maximum of +/- 1 K.

5

14. An illumination optical unit with a mirror (26) which is produced by a method as
claimed in one of claims 1 to 12 and/or is formed as claimed in claim 13.

15. A projection optical unit with a mirror (26) which is produced by a method as claimed in
one of claims 1 to 12 and/or is formed as claimed in claim 13.

10

16. A microlithographic projection exposure apparatus with an illumination optical unit (4)
as claimed in claim 14 and/or a projection optical unit (10) as claimed in claim 15.

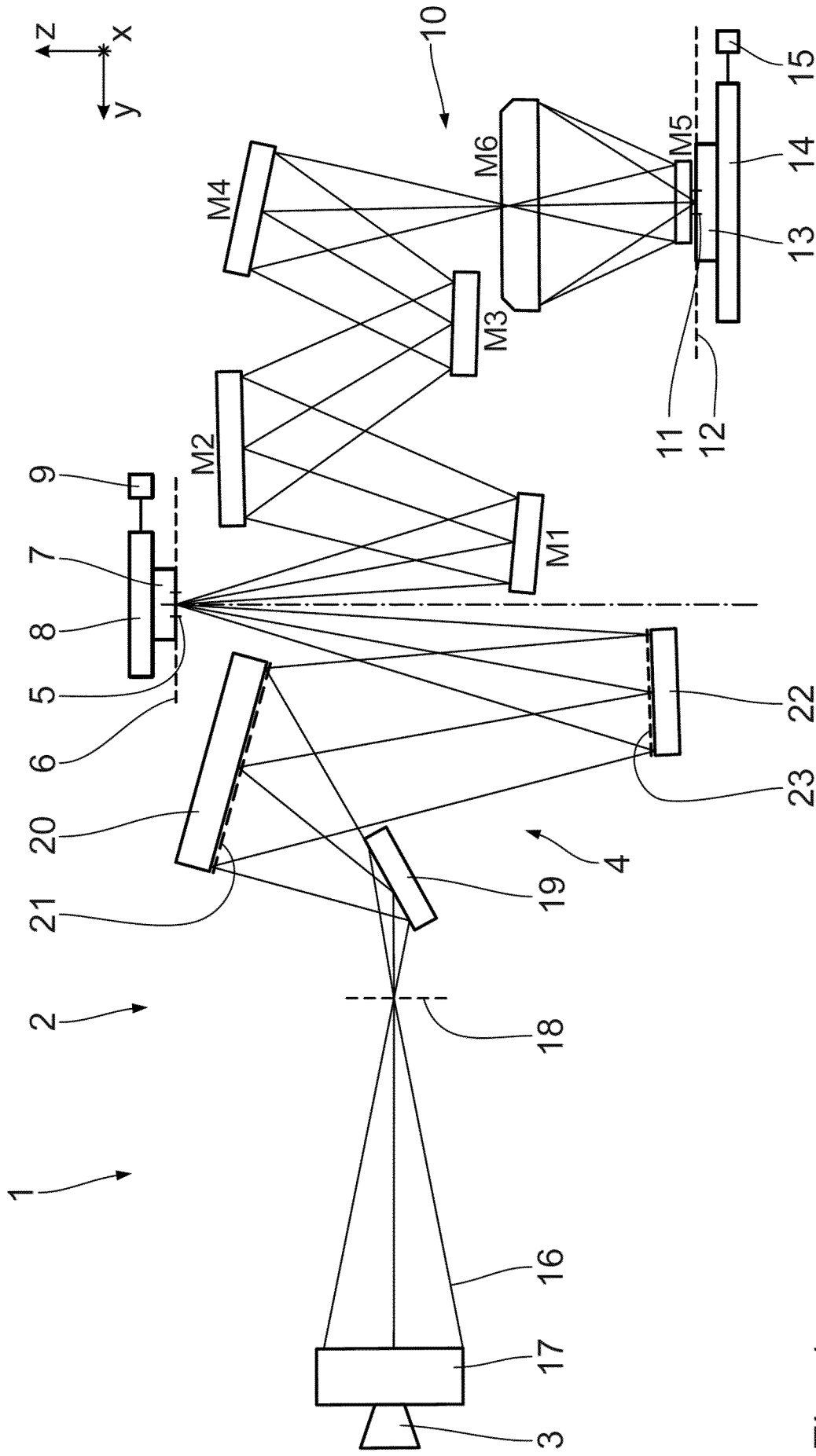


Fig. 1

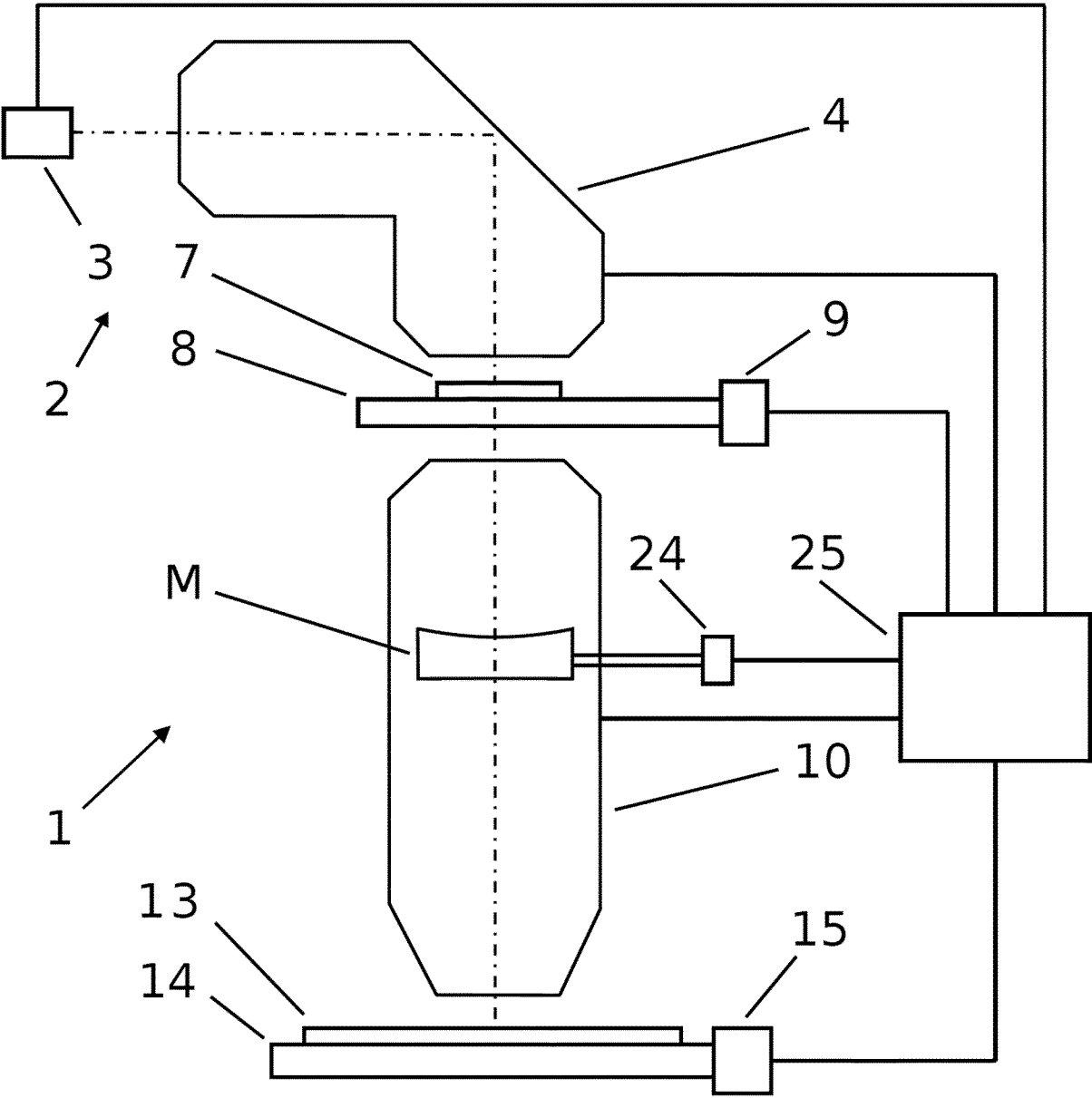
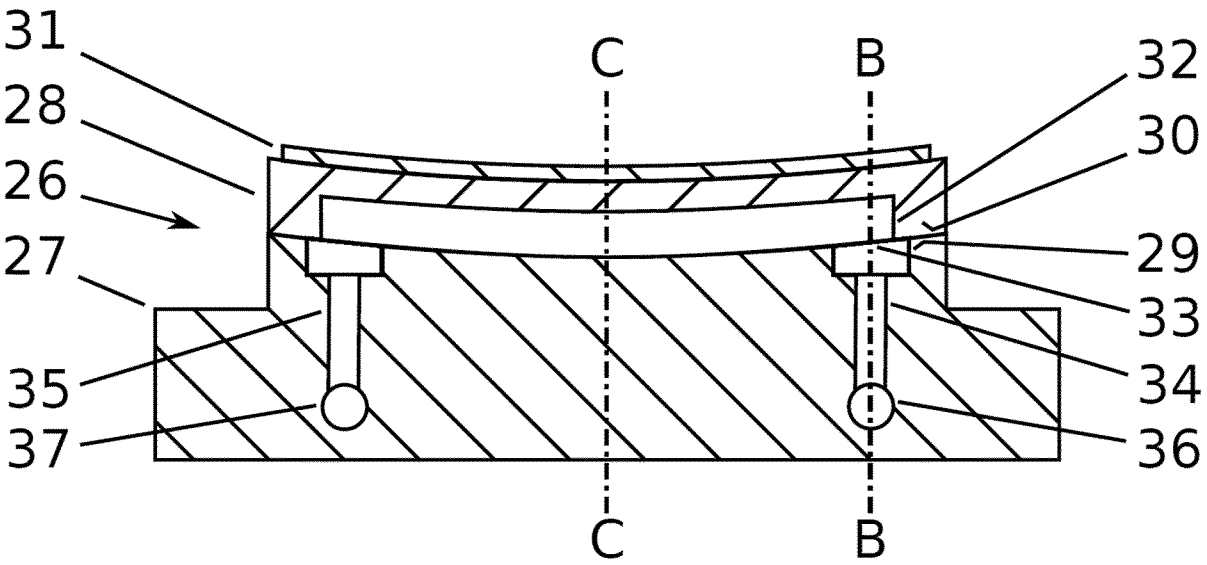
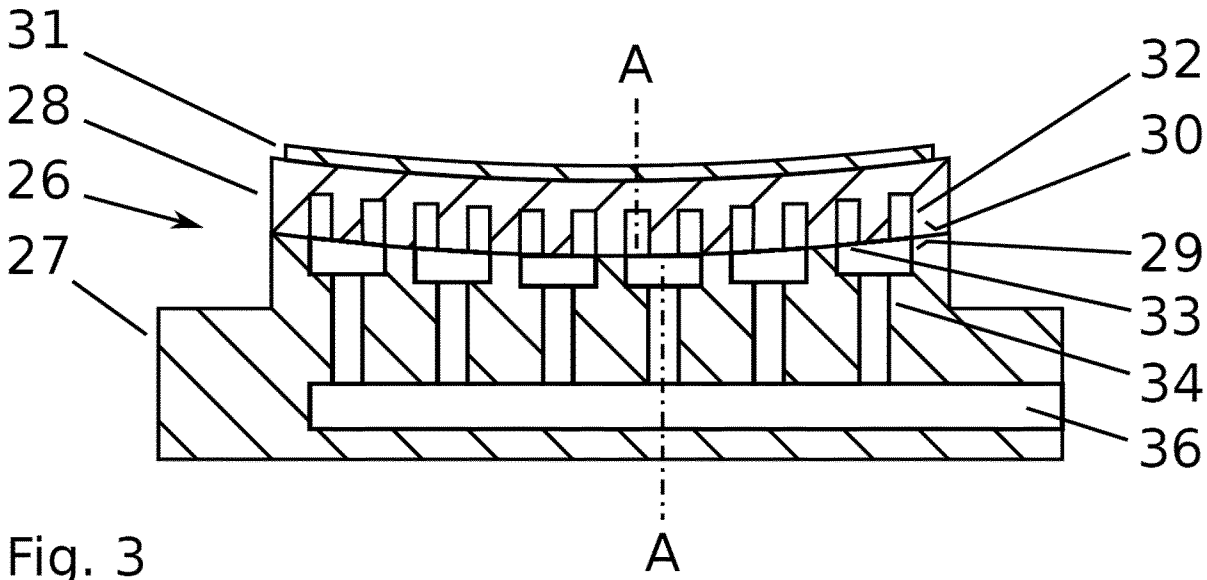


Fig. 2



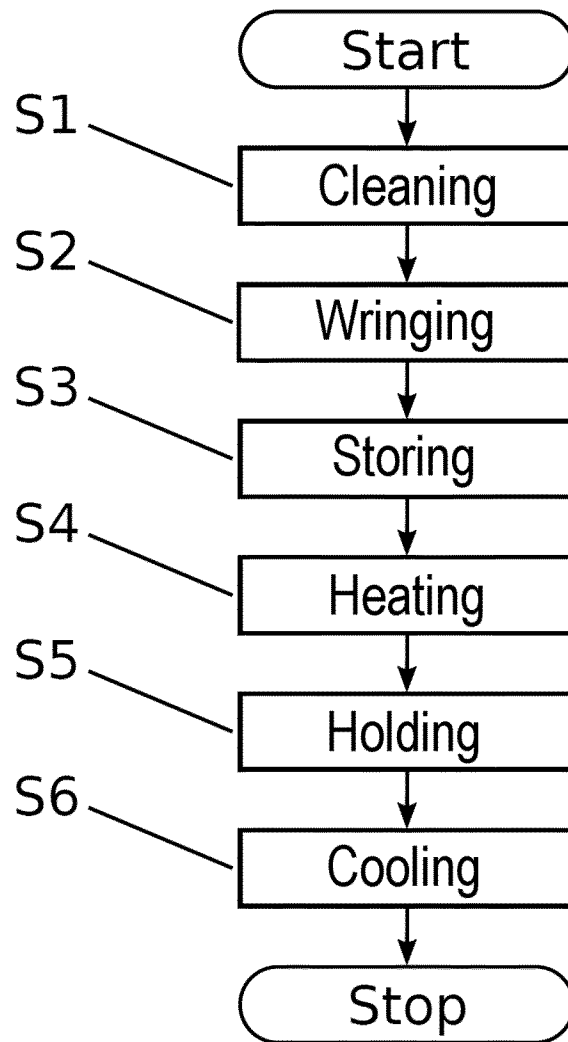


Fig. 5

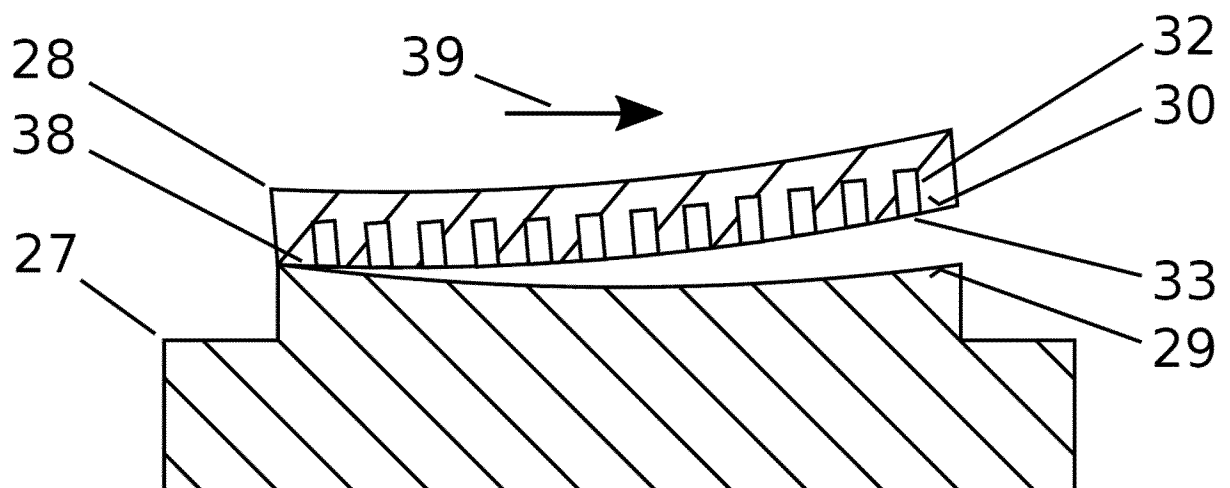


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/051684

A. CLASSIFICATION OF SUBJECT MATTER INV. G03F7/00 G21K1/06 G02B5/08 C03B23/20 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 H05G G21K G02B C03B		
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.
Y	DE 10 2021 203475 A1 (ZEISS CARL SMT GMBH [DE]) 13 October 2022 (2022-10-13) paragraphs [0037], [0134] - [0145], [0175]; claim 13 -----	1-16
Y	US 2013/107239 A1 (CLAUSS WILFRIED [DE]) 2 May 2013 (2013-05-02) paragraphs [0021], [0022], [0034] -----	1-12
Y	US 2011/207592 A1 (DURAN CARLOS [CA] ET AL) 25 August 2011 (2011-08-25) paragraphs [0004], [0021] - [0025] -----	3-5, 7-16
☐ 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 "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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
11 August 2023		23/08/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Eisner, Klaus

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/051684

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