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(54) Title: ARRAY OF CONTROLLABLE MIRRORS

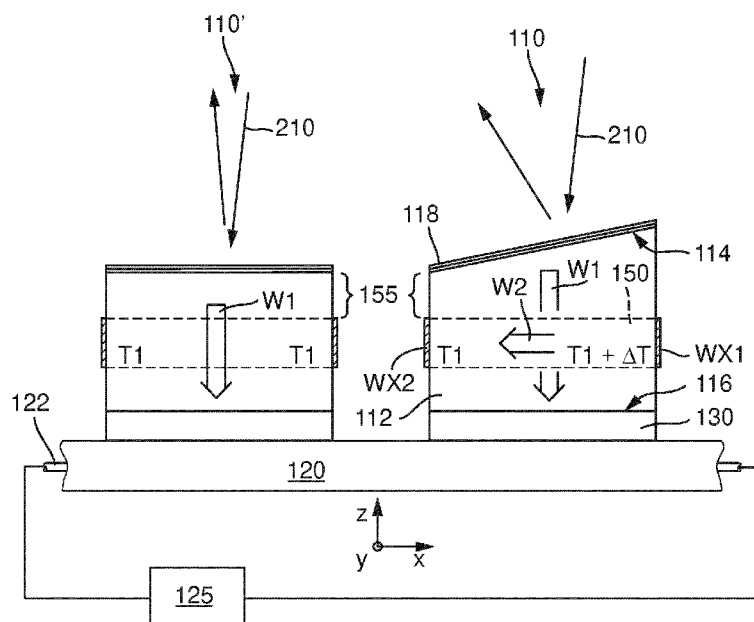


Fig. 2

(57) Abstract: A multi-mirror array has a carrier structure (120), which carries a multiplicity of individual mirror elements (110). A mirror element has a mirror substrate (112), which has a front surface (114) coated with a reflection coating (118) and a rear surface (116) situated opposite the front surface at a distance and facing the carrier structure. Provision is made of a temperature-regulating device for generating a lateral steady-state temperature gradient in a temperature-regulatable zone (150) of the substrate, said zone lying between the front surface and the rear surface, as a response to signals of a control device.



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Description

ARRAY OF CONTROLLABLE MIRRORS

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The following disclosure is based on German Patent Application No.
10 2011 005 840.0 filed on March 21, 2011 which is herewith
incorporated into this application by reference.

10

BACKGROUND

Technical field

15 The invention relates to a controllable multi-mirror array in accordance
with the preamble of claim 1, an optical system comprising a controllable
multi-mirror array in accordance with the preamble of claim 12, and to a
method for operating a controllable multi-mirror array in accordance with
the preamble of claim 14.

20

Description of the prior art

Nowadays predominantly microlithographic projection exposure methods
are used for producing semiconductor components and other finely
25 structured components. In this case, use is made of masks (reticles) or
other patterning devices which carry or form the pattern of a structure to
be imaged, e.g. a line pattern of a layer of a semiconductor component.
The pattern is positioned in a projection exposure apparatus between an
illumination system and a projection lens in the region of the object
30 surface of the projection lens and illuminated with an illumination
radiation provided by the illumination system. The radiation altered by
the pattern passes as projection radiation through the projection lens,

which images the pattern onto the substrate to be exposed, which is coated with a radiation-sensitive layer.

The pattern is illuminated with the aid of an illumination system, which, from the radiation, a primary radiation source, forms an illumination radiation which is directed onto the pattern and which is characterized by specific illumination parameters and impinges on the pattern within an illumination field of defined form and size.

10 In general, depending on the type of structures to be imaged, different illumination modes (so-called illumination setting) are used, which can be characterized by different local intensity distributions of the illumination radiation in a pupil surface of the illumination system.

15 There are various possibilities for setting the desired intensity distribution of the illumination radiation in a pupil surface of the illumination system or a corresponding angular distribution of the illumination light in the illumination field. In general, an illumination system has a pupil shaping unit for receiving radiation from a primary radiation source and for
20 generating a two-dimensional intensity distribution that can be set in a variable fashion in the pupil surface of the illumination system.

Some concepts provide for using in the pupil shaping unit a controllable mirror array in the form of a multi-mirror array (MMA) having a
25 multiplicity of individual mirror elements which are carried by a common carrier structure and which can be tilted independently of one another in order to alter the angular distribution of the radiation incident on the totality of the mirror elements in a targeted manner such that the desired spatial illumination intensity distribution arises in the pupil surface.

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In order to be able to set the geometrical reflection properties of a controllable mirror array in a targeted manner, a controllable mirror array

generally has for each mirror element an actuator arrangement coupled to the mirror element and serving for controllably altering the position of the mirror element relative to the carrier structure carrying the mirror elements. Furthermore, provision is made of a control device for
5 controlling actuating movements of the actuator arrangement. In the absence of control signals, the mirror elements assume their respective zero position. Under the supervision of the control device, the orientation and/or the position of the mirror surface of the mirror element can be altered in a targeted manner proceeding from the zero position. An
10 actuator arrangement has one or a plurality of actuator elements which can be activated in a targeted manner and the actuation or activation of which leads to the actuating movement of the actuator arrangement.

WO 2009/100856 A1 discloses multi-mirror arrays having a multiplicity of
15 individual mirror elements which are in each case connected to an actuator in such a way that they can be tilted separately from one another about at least one tilting axis. In one exemplary embodiment, the actuators are embodied as electrically drivable piezo-actuators.

20 The patent US 6,977,718 B1, too, discloses multi-mirror arrays whose individual mirror elements can be tilted with the aid of piezoelectric actuators.

The patent application US 2008/0100816 A1 discloses illumination
25 systems for microlithography which use a multi-mirror array whose individual mirror elements can be tilted with the aid of piezoelectric or electrostatic actuators.

The patent application US 2006/0103908 A1 discloses multi-mirror
30 arrays whose individual mirror elements can be tilted with the aid of magnetic actuators or Lorentz actuators.

The patent US 6,428,173 B1 discloses microelectromechanical structures (MEMS), designed such that an individual mirror element or many mirror elements of a mirror array can be moved in a targeted manner as a reaction to a selective thermal actuation or activation by thermally activatable actuator elements. For thermally activating an actuator element, an electric current can be conducted through at least part of the actuator element in order to directly electrically heat the latter. An indirect thermal activation with the aid of an external heating device is mentioned as an alternative.

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The patent application WO 2010/003527 A1 discloses multi-mirror arrays comprising individually tiltable mirror elements which are carried by a carrier structure divided into two or more partial regions that can be tilted relative to one another. As a result, at least two of the mirror elements have a different orientation of their mirror surface in their zero position.

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US 2007/0165202 A1 (corresponding to WO 2005/026843 A2) and WO 2008/131928 A1 or EP 1 262 836 A1 disclose examples of the use of multi-mirror arrays in illumination systems for microlithographic projection exposure apparatuses which operate in the deep ultraviolet range (DUV range).

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The use of multi-mirror arrays in illumination systems for radiation from the extreme ultraviolet range (EUV) is disclosed for example in the patent US 6,977,718 B1 or in the patent applications DE 2007 041 004 A1 and DE 10 2008 009 600 A1. In this case, DE 10 2008 009 600 A1 proposes using two controllable multi-mirror arrays in an illumination system, of which multi-mirror arrays one serves as a field facet mirror and the other as a pupil facet mirror.

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The requirements made of the accuracy of the orientation of the individual mirror surfaces of a mirror array are very stringent particularly in the case of applications in the field of microlithography. Typical requirements made of the accuracy of the orientation can be of the order
5 of magnitude of one or a few microradians (μrad) ($1 \text{ radian} = 1 \text{ rad} = 180^\circ/\pi$) both at room temperature and in the heated state during operation. This angular accuracy corresponds to typically required positioning accuracies in the range of a few nanometers, wherein these accuracies should preferably also be complied with under the influence
10 of temperature variations such as can be generated by the electromagnetic radiation used during projection exposure for example during the operation of a projection exposure apparatus. A misorientation of individual or a plurality of mirror surfaces of a mirror array can have various causes.

15 Misorientations can for example already occur during the mounting of a mirror array within an optical system. Over the lifetime of the optical system, relaxation effects that bring about an irreversible alternation of the orientation can additionally occur on account of repeated thermal
20 cycling stress. During operation, reversible misorientations can occur on account of temperature changes, for example. Misorientations of the mirror surfaces influence the geometrical reflection behavior of the mirror array and can e.g. disadvantageously affect the angular distribution of the radiation in the beam reflected by the mirror array.

25 Therefore, there is a need for controllable mirror arrays which permanently allow the geometrical-optical properties of a beam influenced by the mirror array to be set as exactly as possible.

30 PROBLEM AND SOLUTION

A problem addressed by the invention is that of providing a controllable multi-mirror array wherein the problems described above can be reduced or avoided. In particular, disadvantages which can result from incorrect positions of mirror elements are intended to be avoided or
5 reduced.

In order to solve this problem, the invention provides a controllable multi-mirror array comprising the features of claim 1. Furthermore, an optical system comprising a controllable multi-mirror array comprising the
10 features of claim 12 and a method for operating a controllable multi-mirror array comprising the features of claim 14 are provided.

Advantageous developments are specified in the dependent claims. The wording of all the claims is incorporated by reference in the content of
15 the description.

A comparable multi-mirror array according to the claimed invention has a carrier structure, which carries a multiplicity of individual mirror elements. A mirror element has a mirror substrate, which has a front surface coated
20 with a reflection coating and a rear surface situated opposite the front surface at a distance and facing the carrier structure. The front surface coated with reflection coating forms the (reflective) mirror surface of the individual mirror element. The front surface or mirror surface can be flat, such that the mirror element forms a plane mirror. The front surface can also be curved convexly or
25 concavely in one or a plurality of directions. The front surface is prepared with optical quality and carries the reflection coating, the material or material combination and construction of which determine the optical reflection properties of the mirror element, in particular the reflectance thereof. The reflection coating can be constructed, for example, such that it has a high
30 reflectance for radiation from the extreme ultraviolet range (EUV). A reflection coating having a reflective effect in the deep ultraviolet range (DUV) can also be involved.

The mirror array includes a temperature-regulating device for generating a lateral steady-state temperature gradient in a temperature-regulatable zone of the substrate, said zone lying between the front surface and the rear surface, as a response to signals of a control device. In this case, the term "lateral temperature gradient" denotes a temperature gradient whose essential component or whose temperature gradient vector is directed at least approximately perpendicularly to a normal to the front surface. The temperature gradient can be generated and/or maintained by a heat flow whose flow direction runs substantially parallel to the front surface. In this case, the temperature-regulating device is designed such that within the mirror substrate it is possible to actively maintain a thermal imbalance in a lateral direction (transverse direction). For this purpose, by way of example, one side of the mirror substrate can be greatly heated, while the opposite side is heated only weakly or is not heated at all, or is even cooled. In this case, a temperature gradient from the warmer to the colder side is established. On account of the thermal expansion of the substrate material, within the temperature-regulatable zone, a greater thermal expansion results on the warmer side than on the colder side, wherein the extent of thermal expansion decreases continuously from the warmer to the colder side without abrupt changes. The non-uniform thermal expansion in the region of the temperature-regulatable zone has the effect that the shape of the mirror substrate varies in a manner that can be defined by predefinition of the temperature gradient, wherein to a first approximation a global tilting of the front surface of the mirror substrate relative to the rear surface about a (virtual) tilting axis arises which runs substantially perpendicularly to the direction of the heat flow and more or less perpendicularly to a normal to the front surface. This thermally induced change in shape of the mirror substrate is fully reversible and, in principle, can be repeated as often as desired with a reproducible result.

By setting a steady-state temperature gradient within the mirror substrate, it is thus possible for spatially separate regions to thermally expand to different extents, thus resulting in an effective tilting or rotation of the front surface, serving as mirror surface, in relation to the rear surface. The correlation between the orientation of the temperature gradient and the resultant tilting of the front surface relative to the rear surface is substantially determined by the system geometry, by the substrate material and by and the type of asymmetrical introduction of thermal energy into the mirror substrate.

In order to achieve a sufficiently great tilting of the mirror surface relative to the rear surface even in the case of moderate temperature gradients, it is provided in some embodiments that the mirror substrate, at least in the region of the temperature-regulatable zone, consists of a substrate material having a coefficient of thermal expansion of at least $1 \cdot 10^{-6} \text{ K}^{-1}$ at room temperature (20°C). Materials having good thermal conductivity and a coefficient of thermal expansion of at least $10 \cdot 10^{-6} \text{ K}^{-1}$ are preferably used. By way of example, a semiconductor material, such as e.g. silicon, or silicon carbide, or a metallic material, such as e.g. aluminum, tungsten or copper, can be used as substrate material. When using materials having good thermal conductivity, what can be achieved is that during the heating of temperature-regulating elements, the temperature at the front surface covered with a possibly temperature-sensitive reflection coating does not rise above a tolerable temperature limit of e.g. 200°C. High coefficients of thermal expansion contribute to the fact that tiltings of sufficient magnitude can be obtained even in the case of relatively moderate temperature differences.

In preferred embodiments, the substrate dimensions, the substrate material and the temperature-regulating device are coordinated with one another in such a way that for the thermally induced tilting a sensitivity S of the order of magnitude of $1 \mu\text{rad/K}$ is obtained. In the case of a

sensitivity $S = 1 \mu\text{rad/K}$, a temperature difference $\Delta T = 1 \text{ K}$ between opposite sides of the substrate produces a tilting of the front surface by $1 \mu\text{rad}$. Preferably, the sensitivity S is in the range of between $0.3 \mu\text{rad/K}$ and $90 \mu\text{rad/K}$, in particular between $1 \mu\text{rad/K}$ and $30 \mu\text{rad/K}$.

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Preferably, an intermediate region that is substantially not temperature-regulatable by the temperature-regulating device lies between the temperature-regulatable zone and the front surface. The heat flow generated by the temperature-regulating device runs, in the absence of further heat sources or heat sinks, substantially within the temperature-regulatable zone, such that hardly any heat flows away into adjacent zones. If a sufficiently large intermediate region lies between the temperature-regulatable zone and the front surface, the side surfaces of which intermediate region are not heated, what can be achieved is that the form of the front surface is practically not altered by the temperature regulation. Therefore, thermally induced deformations of the front surface serving as mirror surface do not occur, such that the alteration of the effect of the heated mirror element results exclusively from the change in the orientation of the reflectively coated front surface. The temperature-regulatable zone can lie e.g. centrally between the front surface and the rear surface, if appropriate also closer to the rear surface than to the front surface.

In some embodiments, provision is made of a cooling device for actively cooling the carrier structure. The carrier structure can contain coolant channels, for example, through which a liquid or gaseous cooling fluid is conducted in order to dissipate heat from the carrier structure. Electrical cooling by means of Peltier elements or the like is also possible. Given sufficiently good heat conduction contact between the mirror substrate and the carrier structure, the carrier structure thus acts as a heat sink and heat is dissipated from the mirror substrate away from the front surface in the direction of the rear surface. The cooling device in

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interaction with the temperature-regulating device has the effect that the heat introduced, if appropriate, by the temperature-regulating device flows away predominantly in the direction of the rear surface of the mirror substrate, such that the asymmetrical deformation of the front surface by the temperature-regulating device is negligible. Moreover, the cooling device contributes to extracting from the mirror substrate heat which can result on account of absorption of the radiation impinging on the reflection coating in the region of the mirroring front side of the mirror element. This can contribute to the long-term stability of the optical properties of the mirror element.

The mirror substrate can be directly connected to the carrier structure, preferably areally. It can consist of the same material as the carrier structure and, if appropriate, be embodied in one piece (integrally) with the latter. An integral configuration allows a particularly good heat transfer between mirror substrate and carrier structure. The mirror array can be produced by a lithography process, for example. In some embodiments, a thermally conductive intermediate structure is arranged between the carrier structure and the mirror substrate. Said intermediate structure can serve as a thermal/mechanical interface between the material of the carrier structure and the material of the mirror substrate, which possibly deviates from the material of the carrier structure. The intermediate structure should allow the best possible heat transfer between mirror substrate and carrier structure; it is therefore preferably areally extended. With the aid of an intermediate structure, in some embodiments, during the production of the mirror array, an alignment of the orientation of the mirror substrate relative to the carrier structure is possible before the mirror substrate is fixed to the carrier structure. The intermediate structure can e.g. contain an adhesive layer or a solder layer or be formed by such. A mechanical fixing structure can also be provided, which maximizes the contact area with respect to the carrier

structure. Alternatively or additionally, the intermediate structure can have an alignable mechanical articulation arrangement.

The temperature-regulating device can be constructed in various ways.

5 In some embodiments, the mirror substrate has side surfaces and an electrothermal transducer is provided on at least one of the side surfaces in the region of the temperature-regulatable zone. In this case, the term “electrothermal transducer” denotes a temperature-regulating element which can be heated or cooled with the aid of electric current. This can
10 be, for example, a resistance heating element or a Peltier element. While in the case of a resistance heating element a DC or AC current conducted through leads to heating (temperature increase), a Peltier element, depending on the polarity of the voltage present, can optionally serve as a heating element (for increasing temperature) or as a cooling
15 element (for decreasing temperature). Preferably, there is an areal contact between the electrothermal transducer and the side surface of the mirror substrate, such that via the contact area per unit time large quantities of heat can be introduced into the mirror substrate or extracted from the mirror substrate.

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Preferably, electrothermal transducers are fitted in pairs on the mirror substrate, wherein a first electrothermal transducer of a first pair is arranged on a first side surface and a second electrothermal transducer of the first pair is arranged on a second side surface situated opposite in
25 a first direction. As a result, the flow of heat can be controlled particularly well in the region between the electrothermal transducers and, by targeted heating and/or cooling of the electrothermal transducers of a pair, it is possible to set temperature gradients of different magnitudes along the first direction.

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Preferably, at least one second pair of electrothermal transducers is provided, which are arranged on opposite side surfaces of the mirror

substrate in a second direction running transversely, in particular perpendicularly, with respect to the first direction defined by the first pair of electrothermal transducers. The transducers of the pairs can be driven independently of one another. As a result, two or more differently oriented virtual tilting axes are possible, such that the front surface can be inclined practically in any desired directions relative to the rear surface.

In some embodiments, the effect of the cooling device of the carrier structure is sufficient to enable the orientation of the mirror substrate exclusively by the use of electrothermal transducers without heat sink functionality. In such embodiments, a pairwise arrangement of the transducers is not necessary. For supervising the orientation of the mirror substrates in any desired fashion, it is possible to use three or more transducers.

The temperature-regulating device can be the sole manipulator device for influencing the orientation of the reflective front surfaces of the mirror elements of the mirror array. Upon activation of the temperature-regulating device, for each mirror surface the orientation thereof can be set with high accuracy in the μ rad range. This enables, for example, a fine alignment of the individual mirror surfaces of the mirror array relative to one another. In this way, by way of example, a desired reflection geometry of the entire mirror array can be set and permanently maintained. It is also possible to dynamically alter the relative orientations of the mirror surfaces of the mirror elements with the aid of the temperature-regulating device. By way of example, in the case of mirror substrates having typical lateral dimensions of between 1 mm and 10 mm, relaxation times or switching times of between 1 sec and 10 sec can readily be realized as necessary.

In some embodiments, for obtaining the required orientation accuracies it suffices to control the temperature-regulating device on the basis of predefined values, for example from a look-up table (open loop control). In other embodiments, the multi-mirror array is incorporated into a closed loop control system by which the setting of the desired orientation for individual mirror surfaces of the mirror elements can be monitored and regulated. For this purpose, in some embodiments, provision is made of a measuring device connected to the control device and serving for determining the orientation of the front surface and for generating measurement signals representing the orientation of the front surface, wherein the control device is configured for controlling the temperature-regulating device on the basis of the measurement signals. This enables an exact orientation of the individual mirror elements even under changing operating conditions.

The multi-mirror array can be designed overall as a plane mirror. In this case, the mirror surfaces of all the mirror elements, with the temperature-regulating device switched off, lie as precisely as possible in a common plane. The carrier structure can have a plane surface for carrying the mirror elements. It is also possible to design the multi-mirror array overall as a curved mirror wherein the totality of all the mirror surfaces nominally lies on a common concavely or convexly curved surface. Misalignments from the desired orientation can be corrected by means of the temperature-regulating device in any case.

The invention also relates to an optical system comprising a multiplicity of optical elements, which is characterized in that the optical system contains at least one multi-mirror array of the type described in this application. The optical system can be e.g. an optical system for a projection exposure apparatus for microlithography. In particular, the illumination system of a projection exposure apparatus can be involved. The mirror array can contribute, as an element of a pupil shaping unit as

a spatially resolving light modulation device, to setting a predefinable local illumination intensity distribution in a pupil surface of the illumination system. Alternatively or additionally, the mirror array can e.g. also be used as facet mirrors having nominally invariable relative orientation of the individual mirrors.

The invention also relates to a method for operating a controllable mirror array comprising a carrier structure, which carries a multiplicity of individual mirror elements, wherein a mirror element has a mirror substrate, which has a front surface coated with a reflection coating and a rear surface situated opposite the front surface at a distance and facing the carrier structure. The method is characterized by generating a lateral steady-state temperature gradient in a temperature-regulatable zone of the substrate, said zone lying between the front surface and rear surface, as a response to signals of a control device.

These and further features emerge not only from the claims but also from the description and the drawings, wherein the individual features can in each case be realized by themselves or as a plurality in the form of subcombinations in an embodiment of the invention and in other fields and can constitute advantageous and inherently protectable embodiments. Exemplary embodiments are illustrated in the drawings and are explained in greater detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

- Fig. 1 shows an excerpt from an embodiment of a controllable multi-mirror array;
- Fig. 2 shows a schematic vertical section through two mirror elements of a multi-mirror array, wherein the left mirror element is shown in a thermally non-activated neutral position and the right mirror

element is shown in a thermally activated position with a tilted mirror surface;

5 Fig. 3 shows an experimentally determined diagram concerning the time dependence of the tilting of a mirror surface with the mirror substrate being asymmetrically heated to different extents;

10 Fig. 4 shows an experimentally determined diagram concerning the dependence of the tilting of a mirror surface on the electrical heating power;

15 Fig. 5 schematically shows an EUV microlithography projection exposure apparatus comprising a controllable mirror array in accordance with one embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1 illustrates, in schematic, obliquely perspective illustration, an excerpt from an embodiment of a controllable multi-mirror array (MMA)
20 100. The multi-mirror array has a multiplicity of individual mirror elements 110, which are fixed to the front side of a common carrier structure 120 and are carried by the latter. In the case of the example, the carrier structure consists of a torsionally stiff material having high thermal conductivity, such as e.g. silicon, silicon carbide (SiC), or a
25 metal, such as aluminum.

Each of the mirror elements has a parallelepipedal mirror substrate 112, which, in the case of the example, respectively as a monolithic block consists of a substrate material having relatively good thermal
30 conductivity and having a coefficient of thermal expansion α of more than $1 \cdot 10^{-6} \text{ K}^{-1}$. In the case of the example, the mirror substrate consists of a metallic material ($\alpha > 20 \cdot 10^{-6} \text{ K}^{-1}$); it can also consist of a

semiconductor material, such as e.g. silicon. The mirror substrate has a flat front surface 114 on its side facing away from the carrier structure 120, and a likewise flat rear surface 116 at the opposite side facing the carrier structure. The vertical distance between front surface and rear surface determines the substrate thickness, which can be e.g. between 1 mm and 10 mm. The front surface and the rear surface each have a rectangular, in particular substantially square, form having edge lengths of the order of magnitude of the substrate thickness.

10 The front surface is processed with optical quality, i.e. with very low surface roughness, and coated with a multilayer reflection coating 118, which, in the case of the example, has a reflective effect for radiation from the extreme ultraviolet range (EUV) and can comprise, for example, alternating layer pairs of molybdenum/silicon or ruthenium/silicon and, if appropriate, additional layers.

In the case of the example, the mirror substrates are not directly fixed to the carrier structure 120, but rather are carried by an intermediate structure 130, which is arranged between the carrier structure and the mirror substrate and forms a thermal/mechanical interface. The intermediate structure can comprise a layer (e.g. adhesive layer or solder material layer) or a block composed of a material which has good thermal conductivity and which differs from the material of the mirror substrate and/or from the material of the carrier structure.

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The carrier structure 120, which has a, for example flat, front side serving as a fixing surface for the mirror elements, can be actively cooled with the aid of a cooling device. For this purpose, coolant channels 122 are provided in the carrier structure 120, which coolant channels, in the mounted state of the mirror array, are connected to a coolant source 125 (Fig. 2) and through which coolant channels, during

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the operation of the mirror array, cooling liquid or some other cooling fluid can flow.

5 The front surfaces of the mirror substrates, said front surfaces being provided with reflection coating, form the respectively square mirror surfaces of the mirror array. Said mirror surfaces are distributed in the manner of a two-dimensional matrix in the form of rows and columns substantially in an area-filling fashion over a larger surface, wherein small distances of the order of magnitude of a few micrometers can
10 remain in each case between adjacent mirror surfaces. The reflectively coated front surfaces (mirror surfaces) form in their totality a faceted mirror surface or a facet mirror, the geometrical reflection properties of which are determined by the orientation of the individual mirror surfaces.

15 The number of mirror elements (individual mirrors or facets) can vary depending on the application. It is possible to provide e.g. between 1000 and 10 000 individual mirror elements, but if appropriate also significantly more, e.g. between 50 000 and 1 million or more, or less than 1000, e.g. between 100 and 1000.

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The orientation of the individual flat mirror surfaces can be described by the orientation of their respective surface normals 113 in the case of the example. The orientation of the surface normals is the same at all locations of the mirror surface in the case of a flat mirror surface. In the
25 case of concavely or convexly curved mirror surfaces that are likewise possible, the orientation can be described for example by the orientation of the surface normal in the mirror center or by the average orientation of the surface normals for the curved mirror surface.

30 In each of the mirror elements, the orientation of the reflective front surface relative to the rear surface 116 facing the carrier structure 120 can be changed in a continuously variable manner and in different tilting

directions in a targeted manner by tilting. For this purpose, a temperature-regulating device is provided, which will now be explained in greater detail primarily in connection with the mirror element shown at the front on the right in Fig. 1 and in association with Fig. 2.

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Fig. 2 shows a schematic vertical section through two mirror elements 110, 110' of a multi-mirror array, wherein the left mirror element 110' is shown in a thermally non-activated neutral position and the right mirror element 110 is shown in a thermally activated position with a tilted mirror surface.

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The temperature-regulating device is a thermoelectric device that is able, in a temperature-regulatable zone 150 lying between the front surface 114 and the rear surface 116, to establish a lateral temperature gradient running between opposite side surfaces of the mirror substrate and to maintain it in a steady state as necessary over a predefinable time duration. The upper and lower boundaries of the temperature-regulatable zone are indicated by dashed lines in Fig. 2. In order to generate lateral temperature gradients, electrothermal transducers WX1, WX2, WY1 and WY2 in the form of areally applied resistance heating elements are provided on the side surfaces of the mirror substrate. The transducers are all electrically connected via electrical lines to a common control device 160 of the temperature-regulating device and can be supplied with electrical energy in each case independently of one another by the control device 160.

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On the two side surfaces situated opposite one another along a first direction (x-direction), resistance heating elements WX1 and WX2 are respectively applied, which form a first pair of electrothermal transducers. On the mirror surfaces oriented perpendicularly thereto and situated opposite one another along a second direction (y-direction), two further electrothermal transducers in the form of areal resistance

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heating elements WY1 and WY2, respectively, are applied, which jointly form a second pair of electrothermal transducers. In the case of the example, the resistance heating elements applied over a large area on the side surfaces each have a flat rectangular shape and each extend
5 substantially over the entire width of the side surfaces, while the height of the electrothermal transducers (measured parallel to the z-direction) corresponds only to a fraction of the height of the mirror substrate, for example a maximum of 50% or a maximum of 30%. In the case of the example, the electrothermal transducers are fitted approximately
10 centrally between the front surface and the rear surface. The temperature-regulatable zone 150 substantially corresponds to that partial volume of the mirror substrate which is enclosed by the electrothermal transducers.

15 Between the temperature-regulatable zone 150 and the mirroring front surface there is a distance over the entire cross section of the mirror substrate, which distance, in the case of the example, approximately corresponds in terms of the order of magnitude to the height (in the z-direction) of the temperature-regulatable zone. This intermediate
20 region 155 lies outside the temperature-regulatable zone and, during the heating of the resistance heating elements, is not heated or only very slightly heated by the latter. The distance from the front surface is dimensioned with a magnitude such that the front surface remains practically uninfluenced by possible temperature changes in the
25 temperature-regulatable zone.

The function of this arrangement will now be explained primarily in association with Fig. 2. The latter shows a section in the x-z plane through two mirror elements which are applied on the common carrier
30 structure 120 and which are situated in the beam path of an optical system, for example of an illumination system for a projection exposure

apparatus. The used light radiation incident on the mirror surfaces within the optical system is symbolized by arrows 210.

In the case of the mirror element 110' shown on the left, the
5 electrothermal transducers on all four sides of the substrate do not have current applied to them, with the result that substantially the same temperature T_1 prevails in the entire temperature-regulatable zone 150. During the operation of the mirror array, the used light 210 impinges on the reflective mirror surface and is reflected there. Part of the impinging
10 radiation is generally absorbed into the reflection coating, as a result of which heat arises in the region of the front surface. Said heat is substantially dissipated through the substrate in the direction of the cooled carrier structure. Consequently, a temperature gradient substantially perpendicular to the front surface (approximately parallel to
15 the surface normal) can be present in the substrate, and leads to a first heat flow W_1 in the direction of the carrier structure.

If the intention is then to change the orientation of the reflective front surface of a mirror element relative to the rear surface, the mirror
20 substrate of said mirror element is heated asymmetrically with the aid of the assigned temperature-regulating device. In the case of the example of the mirror element 110 shown on the right, for this purpose a heating current is conducted for example through the electrothermal transducer WX_1 shown on the right, as a result of which the latter heats up. The
25 electrothermal transducer WX_2 situated opposite in the first direction (x-direction) is not supplied with current, and so no electrical heat arises there. The electrical heating in the region of the right heating element WX_1 generates, within the adjoining partial volume of the substrate, a temperature increase ΔT relative to the opposite side, such that the
30 increased temperature $T_1 + \Delta T$ is established there. This temperature difference between the mutually opposite sides of the mirror substrate generates a temperature gradient transversely through the mirror

substrate and leads to a second heat flow W_2 from the side of the relatively higher temperature to the side having the relatively lower temperature. In this case, the heat flow runs predominantly within the temperature-regulatable zone 150. Dissipation of heat in the direction of the front surface is prevented to the greatest possible extent by the temperature gradient existing between said front surface and the cooled rear surface, such that the front surface is practically not influenced by the second heat flow W_2 introduced with the aid of the electrothermal transducers.

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The lateral temperature gradient within the temperature-regulatable zone leads to an asymmetrical thermal expansion of the substrate material in the region of the temperature-regulatable zone. In this case, the extent of thermal expansion in the vicinity of the hotter electrothermal transducer WX1 is particularly great and decreases continuously in the direction of the opposite side. As a result of the thermally induced expansion of the substrate material acting in all spatial directions, that side of the reflective mirror surface which is assigned to the warmer side (near WX1) is raised relative to the opposite side, such that a tilting of the mirroring front surface relative to the rear surface that remains stationary is established. The virtual tilting axis associated with this tilting runs substantially perpendicular to the temperature gradient generated, i.e. parallel to the y-direction.

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In a corresponding manner, it is also possible to generate a tilting of the mirroring front surface in the opposite direction. It is also possible to generate a tilting of the mirror surface about a virtual tilting axis directed parallel to the x-direction. For this purpose, with the aid of the control device, current is applied asymmetrically to the two transducer elements WY1, WY2 situated opposite one another in the y-direction, such that, for example, the substrate heats up to a greater extent in the vicinity of the transducer element WY1 shown at the front in Fig. 1 than in the

region of the transducer element WY2 situated opposite. This would bring about a tilting toward the rear in Fig. 1.

Each of the transducers fitted to a mirror substrate can be driven independently of the other transducers fitted to the mirror substrate, with the aid of the control device 160. As a result, the heating powers of all the transducers can be set independently from one another. This in turn makes it possible that the front surface can be tilted practically in any desired directions, i.e. about virtual tilting axes oriented in any desired manner. If, by way of example, the transducers WX1 and WY1 discernible on the visible front sides in Fig. 1 are heated, while the transducers WX2, WY2 respectively situated opposite remain free of current, then a lateral temperature gradient will be established within the mirror substrate, the main direction of said temperature gradient lying between the x-direction and the y-direction. If, by way of example, WY1 and WX1 are heated to the same extent, the heat flow will run substantially parallel to the angle bisector centrally between y- and x-direction transversely through the substrate, thus resulting in a virtual tilting axis parallel to the angle bisector perpendicular thereto.

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In the exemplary embodiment, the temperature-regulating device is incorporated into a closed loop control system which allows the desired tilting position of the individual mirror surfaces to be set very exactly and maintained independently of ambient conditions. The closed loop control system comprises an optical measuring device 170 operating according to the autocollimation principle, which measuring device directs a measurement array 172 onto each of the monitored mirror elements, which measurement array, after reflection at the monitored mirror surface, returns to the measuring device and carries information about the present orientation of the reflective mirror surface. From this information, measurement signals representing the orientation of the front surface are generated and are fed back to the control device 140,

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which controls the temperature-regulating device on the basis of said measurement signals (closed loop control).

The actuation principle explained here by way of example makes it possible to set the orientation of the mirror surfaces with an accuracy in the range of 1 microrad (μrad) or less, wherein actuation times in the range of a few seconds, e.g. of less than 10 s, can be obtained.

The following indications can be useful in the design of mirror arrays. In preferred embodiments, the substrate dimensions, the substrate material and the temperature-regulating device are coordinated with one another in such a way that, for the thermally induced tilting, a sensitivity S of the order of magnitude of $1 \mu\text{rad/K}$ is obtained. In the case of a sensitivity $S = 1 \mu\text{rad/K}$, a temperature difference $\Delta T = 1 \text{ K}$ between opposite sides of the substrate generates a tilting of the front surface by $1 \mu\text{rad}$. Preferably, the sensitivity S is in the range of between $0.3 \mu\text{rad/K}$ and $90 \mu\text{rad/K}$, in particular between $1 \mu\text{rad/K}$ and $30 \mu\text{rad/K}$. Temperature differences down to the order of magnitude of $\Delta T = 1 \text{ K}$ can be supervised by control technology with sufficient accuracy and a tenable outlay. Temperatures to the order of magnitude of $T = 200^\circ\text{C}$ or can easily be generated by means of various temperature-regulating elements, e.g. SMD or SMC resistors or heating strips, and are low enough to avoid overheating of the reflection layer. Accordingly, lateral temperature differences between the side surfaces to the order of magnitude of $\Delta T = 100 \text{ K}$ can readily be realized. If consideration is furthermore given to typical substrate dimensions having a ratio of substrate height to substrate width of close to 1, then the sensitivity S is for the first approximation equal to the coefficient of thermal expansion α . Under these conditions, a tiltings of $1 \mu\text{rad}$ would be generated for a substrate material having a coefficient of thermal expansion of $1 \cdot 10^{-6} \text{ K}^{-1}$ given a lateral temperature gradient of $\Delta T = 1 \text{ K}$. The adjustment range for silicon ($\alpha = 2.6 \cdot 10^{-6} \text{ K}^{-1}$) and $\Delta T = 200 \text{ K}$ is then approximately $520 \mu\text{rad}$.

For metals such as e.g. aluminum ($\alpha \approx 23 \cdot 10^{-6} \text{ K}^{-1}$), tiltings right into the mrad range would be possible, in which case the accuracy of the temperature control should then, if appropriate, be below 1 K.

- 5 In an experimental exemplary embodiment, the multi-mirror array had a coolable carrier structure, on which approximately cubic mirror substrates having edge lengths of approximately 5 mm were applied. On some mirror substrates, in a similar manner to that shown on the right in Fig. 2, resistance heating elements were applied areally on two mirror
10 surfaces situated opposite one another in the x-direction. The orientation of the mirroring front surface was determined by means of an autocollimation system. Ever higher electrical powers step by step were progressively applied to one of the resistance heating elements situated opposite one another. The resultant tiltings of the mirroring front surface
15 about the virtual tilting axis running parallel to the y-direction were measured optically. The results of this calibration are illustrated in Fig. 3 and 4.

Fig. 3 shows a diagram in which the time t [s] is indicated on the
20 abscissa and the tilting angle of the mirror surface (in μrad) is indicated on the ordinate. Both the tilting in the x-direction (about a virtual tilting axis running parallel to the y-direction, tilting angle T_Y) and the tilting perpendicular thereto (about a virtual tilting axis running parallel to the x-direction, tilting angle T_X) were measured. Fig. 4 shows a diagram
25 representing the tilting angles T_Y (in μrad) obtained as a function of the electrical heating power P [W] in these experiments. Five different heating powers (namely approximately 0.5 W, approximately 1.5 W, approximately 2.5 W, approximately 4 W and approximately 5.5 W) were set successively. Between the individual heating phases, the
30 temperature-regulating device was switched off again in each case.

The temporal profile of the tilting positions can be gathered from Fig. 3. When the lowest heating power was switched on, a tilting angle of approximately $5\text{ }\mu\text{rad}$ was established after distinctly less than 10 s, which tilting angle then remained substantially constant as long as the heating power remained switched on. After the heating power was switched off, the mirror substrate assumed the original shape again likewise within a few seconds, in the case of which shape the reference tilting angle ($0\text{ }\mu\text{rad}$) was present. After a pause (approximately 1 min), the next higher heating power of 1.5 W was introduced. The tilting angle of approximately $12\text{ }\mu\text{rad}$ associated with this was established within less than 10 s, and said tilting angle remained more or less constant with small fluctuations until the heating power was switched off again. This procedure was repeated for the next higher heating powers. As emerges from the steep flanks of the curve TY in Fig. 3, the tilting position associated with a heating power was in each case established very rapidly (after less than 10 s) and then remained at a more or less constant level, wherein the measured fluctuations of the tilting position were within the scope of the measurement accuracy of the measuring system (approximately $1\text{ }\mu\text{rad}$). After the heating power was switched off, the tilting was in each case completely reset, thereby showing that the process is fully reversible. In the case of the example, up to a heating power of approximately 4 W, a more or less linear relationship between the heating power introduced and the extent of tilting obtained as a result was found. Toward higher heating powers, a deviation from linearity then arises.

It can also be discerned in Fig. 3 that the tilting of the mirror surface takes place practically exclusively in the desired direction, namely about a virtual tilting axis running perpendicular to the temperature gradient generated. This is discernible from the profile of the curve TX showing the corresponding tiltings about a virtual tilting axis running parallel to the x-axis. Although slight deviations from the desired orientation are in

each case manifested when the heating powers are switched on, said deviations are at least one order of magnitude below the level of the desired tilting in the direction perpendicular thereto. In the case of the example, the deviations from the desired orientation (at $TX = 0 \mu\text{rad}$) are
5 in the range of a maximum of 2 to 3 μrad).

The actuation principle illustrated here by way of example and based on a change in shape of the mirror substrate that can be set in a targeted manner enables settings of the orientation of a mirror surface relative to
10 the rear surface of a mirror substrate with extremely high accuracy in the range of μrad . In the experimental example, the obtainable tilting angles were of the order of magnitude of a few tens of μrad , e.g. up to approximately 40 μrad . A set tilting position was able to be set with an accuracy of less than 15%, in particular of less than 10%, of the set
15 tilting angle and permanently maintained. In absolute values, the setting accuracy was typically less than 10 μrad (at the highest absolute tilting angles), in general even less than 5 μrad or even less than 2 μrad . This accuracy of the setting is in this case also designated as the resolution capability of the multi-mirror array in the angle space.

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A multi-mirror array of the type described here by way of example can be used in various ways.

In some embodiments, the setting possibility is used exclusively for
25 alignment purposes. One aim of this use possibility is to set and maintain, for each of the individual mirrors of a mirror array at any time, the zero position desired for the individual mirror, i.e. its desired orientation, with extremely high accuracy. This can be used in the case of a facet mirror, for example, which is intended to have a defined
30 relative orientation of its individual mirror facets that is invariable (in the ideal case) during operation. If such a facet mirror is incorporated into an optical system, misalignments of individual mirror elements can occur as

a result of incorporation. Said misalignments can be corrected with the aid of the temperature-regulating device presented here, by tilting individual mirrors relative to other mirrors by means of non-uniform heating of the corresponding mirror substrates such that they assume
5 their desired orientation (zero position) again. In this case, the temperature-regulating device serves as a control system for the variable setting of the reference position or zero position of each individual mirror element. The thermally set tiltings can be maintained practically in a temporally unlimited manner over large time intervals and
10 corrected further as necessary.

Particularly in the case of applications wherein dynamic tiltings of individual mirror elements in the range of a maximum of 50 to 1400 μrad are desired, a mirror array with temperature-regulating device can also
15 be used for dynamically changing the geometrical reflection properties of a multi-mirror array.

Fig. 5 shows the essential optical components of a microlithography projection exposure apparatus 500. The apparatus comprises an
20 illumination system 510 and a projection lens 530 and is operated with the radiation from a light source 514. The light source 514 can be, inter alia, a laser plasma source or a discharge source. Such light sources generate a radiation 520 in the EUV range, that is to say having wavelengths of between 5 nm and 15 nm. In order that the illumination
25 system and the projection lines can operate in this wavelength range, they are constructed with components reflective to UV radiation.

The radiation 520 emerging from the light source 514 is collected by means of a collector 515 and directed into the illumination system 510.
30 The illumination system here comprises a mixing unit 512, a telescope optical unit 516 and a field shaping mirror 518. The projection lens 530 serves for imaging an object field 552 in the object plane 550 of the

projection lens onto an image field 562 in the image plane 560 of the projection lens. The projection lens here has six mirrors.

The mixing unit substantially consists of two facet mirrors 570, 580. The
5 first facet mirror 570 is arranged in a plane of the illumination system that is optically conjugate with respect to the object plane 550. It is therefore also designated as a field facet mirror. The second facet mirror 580 is arranged in a pupil plane of the illumination system that is optically conjugate with respect to a pupil plane of the projection lens. It
10 is therefore also designated as a pupil facet mirror. With the aid of the pupil facet mirror 580 and the downstream imaging optical assembly comprising the telescope optical unit 516 and the field shaping mirror 518 operated with grazing incidence, the individual mirroring facets (individual mirrors) of the first facet mirror 570 are imaged into the object
15 field 552. EUV projection exposure apparatuses having this or a similar basic construction are known e.g. from WO 2009/100856 A1, the disclosure of which is incorporated by reference in the content of this description.

20 Each of the facet mirrors has a carrier structure that carries a multiplicity of individual mirror elements, that is to say individual mirrors. The mirroring front surfaces thereof form the facets (mirror surfaces) of the facet mirror.

25 At least one of the facet mirrors 570, 580 can have a temperature-regulating device of the type described here in order to ensure the accuracy of the orientation of the individual mirrors under different operating conditions and over the lifetime of the apparatus.

30 In the case of the example, only the pupil facet mirror 580 is equipped with a temperature-regulating device. The latter is connected to a control device 582, which controls the thermally induced tilting of the individual

mirrors. The orientation of the individual mirrors is optically monitored contactlessly by a measuring device 584 connected to the control device. The pupil facet mirror is intended to have a temporally invariable reflection geometry or emission characteristic. If the wanted desired orientation of individual or all facets of the pupil mirror changes in the course of operation, compensation or alignment can be carried out with the aid of the temperature-regulating device incorporated in a closed loop control system by the tilting of mirror surfaces, in order to keep the desired orientation of each of the individual mirrors with a setting accuracy of $\pm 1 \mu\text{rad}$ or less permanently within the tolerance ranges.

In other embodiments, only the field facet mirror is equipped with a temperature-regulating device. Likewise, it is possible for both the field facet mirror and the pupil facet mirror to be equipped with a temperature-regulating device.

Patent claims

1. Multi-mirror array comprising:
a carrier structure (120),
5 which carries a multiplicity of individual mirror elements (110),
wherein a mirror element has a mirror substrate (112), which has a
front surface (114) coated with a reflection coating (118) and a
rear surface (116) situated opposite the front surface at a distance
and facing the carrier structure,
10 characterized by a temperature-regulating device for generating a
lateral steady-state temperature gradient in a temperature-
regulatable zone (150) of the substrate, said zone lying between
the front surface and the rear surface, as a response to signals of
a control device (160).
15
2. Multi-mirror array according to Claim 1, wherein the mirror
substrate (112), at least in the region of the temperature-
regulatable zone, consists of a substrate material having a
coefficient of thermal expansion of at least $1 \cdot 10^{-6} \text{ K}^{-1}$ at room
20 temperature (20°C), wherein the substrate material is preferably a
semiconductor material or a metallic material.
3. Multi-mirror array according to Claim 1 or 2, wherein substrate
dimensions, the substrate material and the temperature-regulating
25 device are coordinated with one another in such a way that for a
thermally induced tilting of the front surface (114) relative to the
rear surface (116), a sensitivity S in the range of between
 $0.3 \mu\text{rad/K}$ and $90 \mu\text{rad/K}$, in particular between $1 \mu\text{rad/K}$ and
 $30 \mu\text{rad/K}$, is present, wherein, in the case of a sensitivity $S =$
30 $1 \mu\text{rad/K}$, a temperature difference $\Delta T = 1 \text{ K}$ between opposite side
surfaces of the substrate produces a tilting of the front surface by
 $1 \mu\text{rad}$.

4. Multi-mirror array according to any of the preceding claims, wherein an intermediate region (155) that is substantially not temperature-regulatable by the temperature-regulating device lies
5 between the temperature-regulatable zone (150) and the front surface (114), wherein the temperature-regulatable zone (150) preferably lies centrally between the front surface and the rear surface or closer to the rear surface than to the front surface.
- 10 5. Multi-mirror array according to any of the preceding claims, wherein provision is made of a cooling device for actively cooling the carrier structure.
- 15 6. Multi-mirror array according to any of the preceding claims, wherein a thermally conductive intermediate structure (130) is arranged between the carrier structure and the mirror substrate, wherein the intermediate structure preferably comprises an adhesive layer or a soldered layer or is formed by such.
- 20 7. Multi-mirror array according to any of the preceding claims, wherein the mirror substrate has side surfaces and an electrothermal transducer (WX1, WX2, WY1, WY2) is arranged on at least one of the side surfaces in the region of the temperature-regulatable zone.
- 25 8. Multi-mirror array according to Claim 7, wherein electrothermal transducers are fitted in pairs on the mirror substrate (112), wherein a first electrothermal transducer (WX1) of a first pair (WX1, WX2) is arranged on a first side surface and a second electrothermal transducer (WX2) of the first pair is arranged on a
30 second side surface situated opposite in a first direction.

9. Multi-mirror array according to Claim 8, wherein at least one second pair (WY1, WY2) of electrothermal transducers is provided, which are arranged on opposite side surfaces of the mirror substrate in a second direction running transversely, in particular perpendicularly, with respect to the first direction defined by the first pair of electrothermal transducers (WX1, WX2).
10. Multi-mirror array according to Claim 8 or 9, wherein the transducers (WX1, WX2, WY1, WY2) of the pairs can be driven independently of one another.
11. Multi-mirror array according to any of the preceding claims, characterized by a measuring device (170) connected to the control device (160) and serving for determining the orientation of the front surface (114) and for generating measurement signals representing the orientation of the front surface, wherein the control device is configured for controlling the temperature-regulating device on the basis of the measurement signals.
12. Optical system comprising a multiplicity of optical elements, characterized in that the optical system comprises at least one multi-mirror array according to any of Claims 1 to 11.
13. Optical system according to Claim 12, wherein the optical system is an optical system of a projection exposure apparatus (500) for microlithography, preferably an illumination system (512) projection exposure apparatus.
14. Method for operating a controllable multi-mirror array comprising a carrier structure, which carries a multiplicity of individual mirror elements, wherein a mirror element has a mirror substrate, which has a front surface coated with a reflection coating and a rear

surface situated opposite the front surface at a distance and facing the carrier structure, characterized by generating a lateral steady-state temperature gradient in a temperature-regulatable zone of the substrate, said zone lying between the front surface and the rear surface, as a response to signals of a control device.

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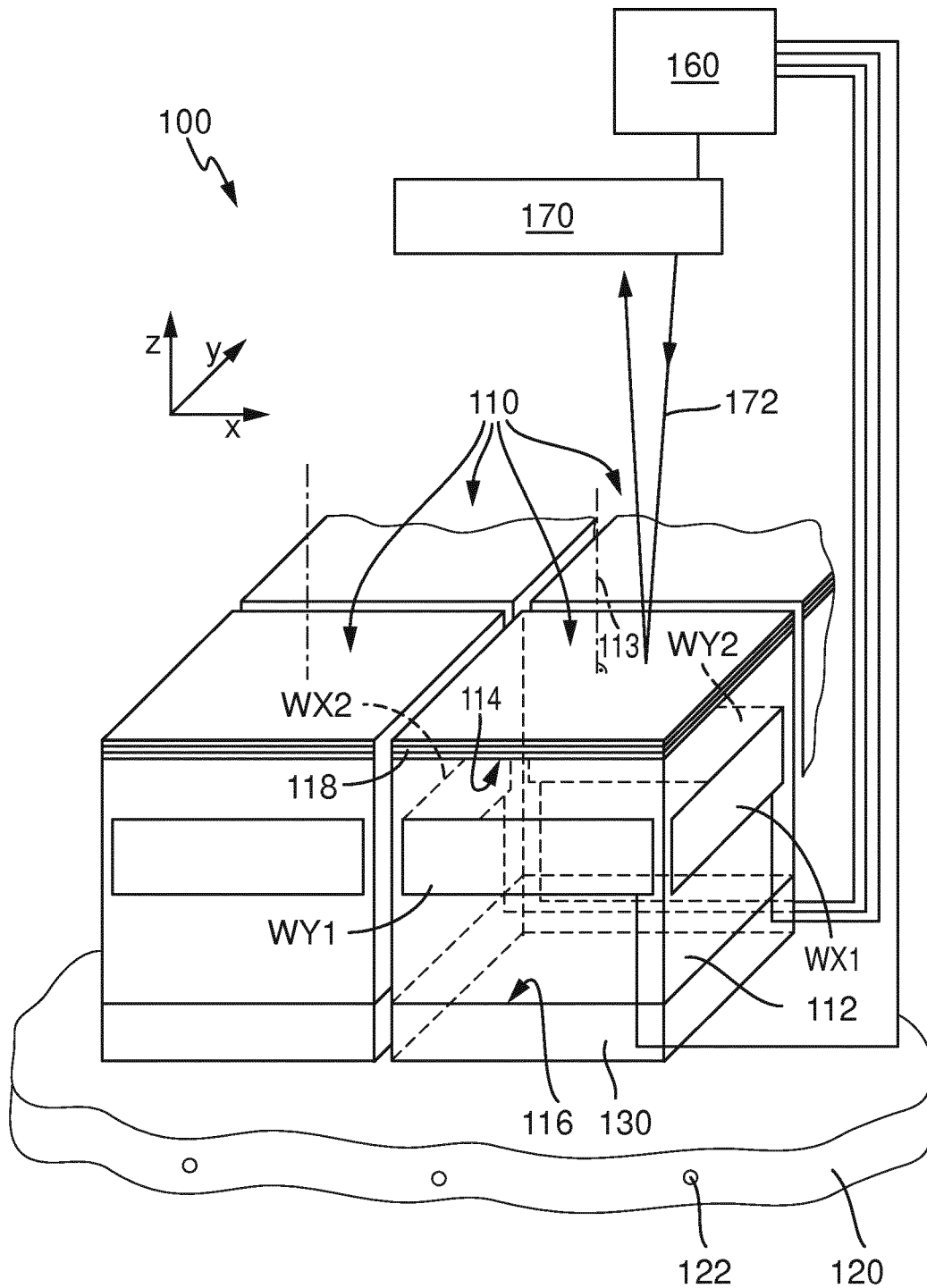


Fig. 1

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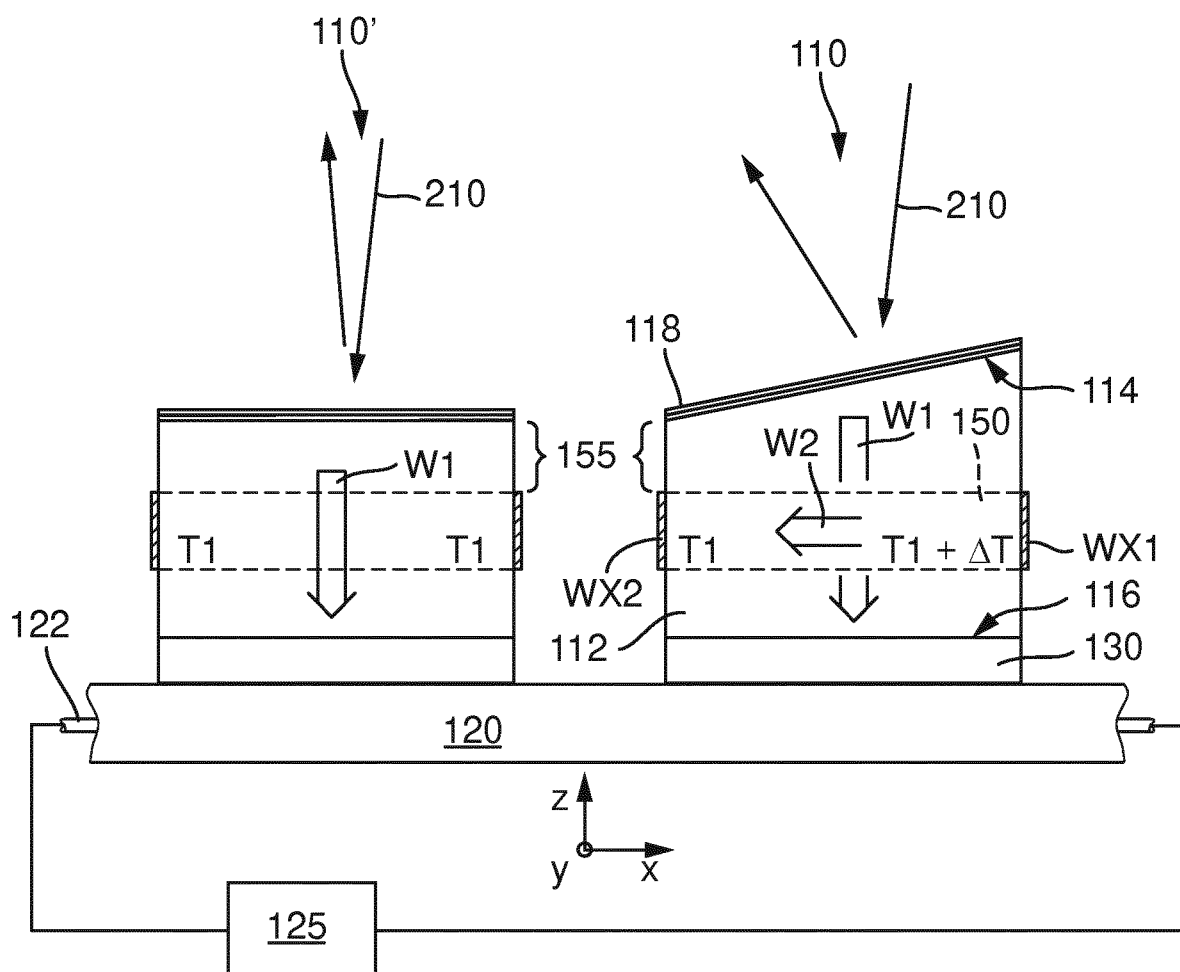


Fig. 2

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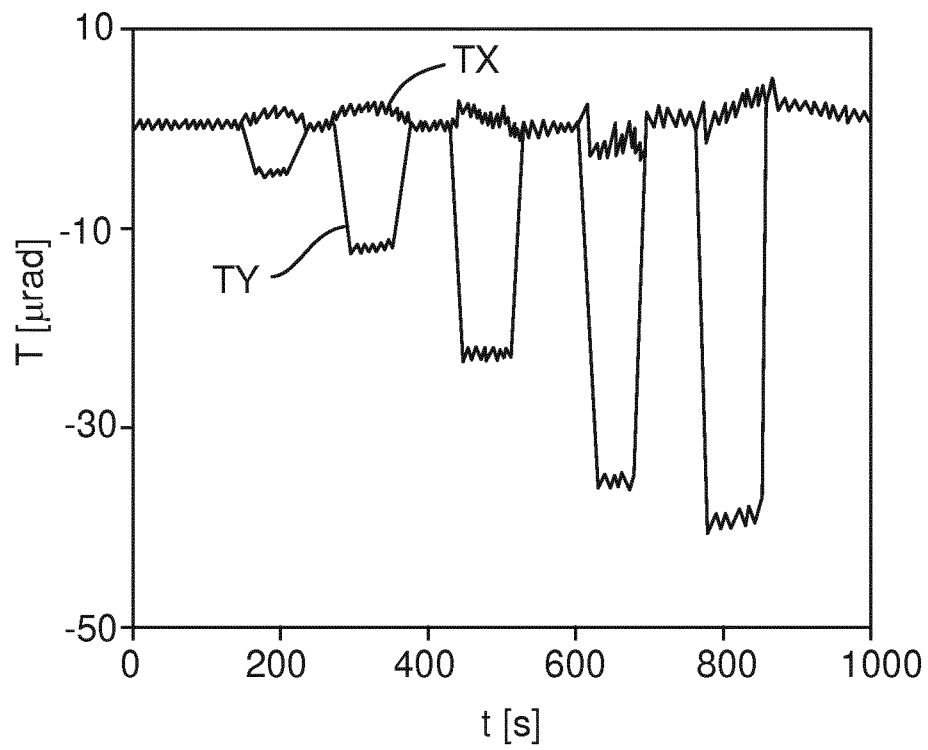


Fig. 3

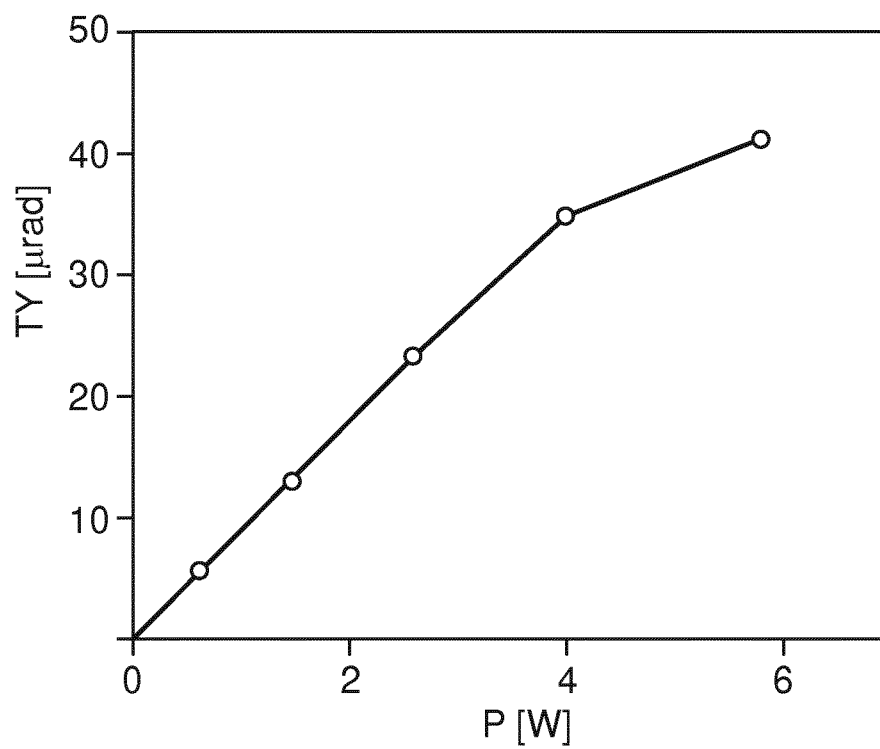


Fig. 4

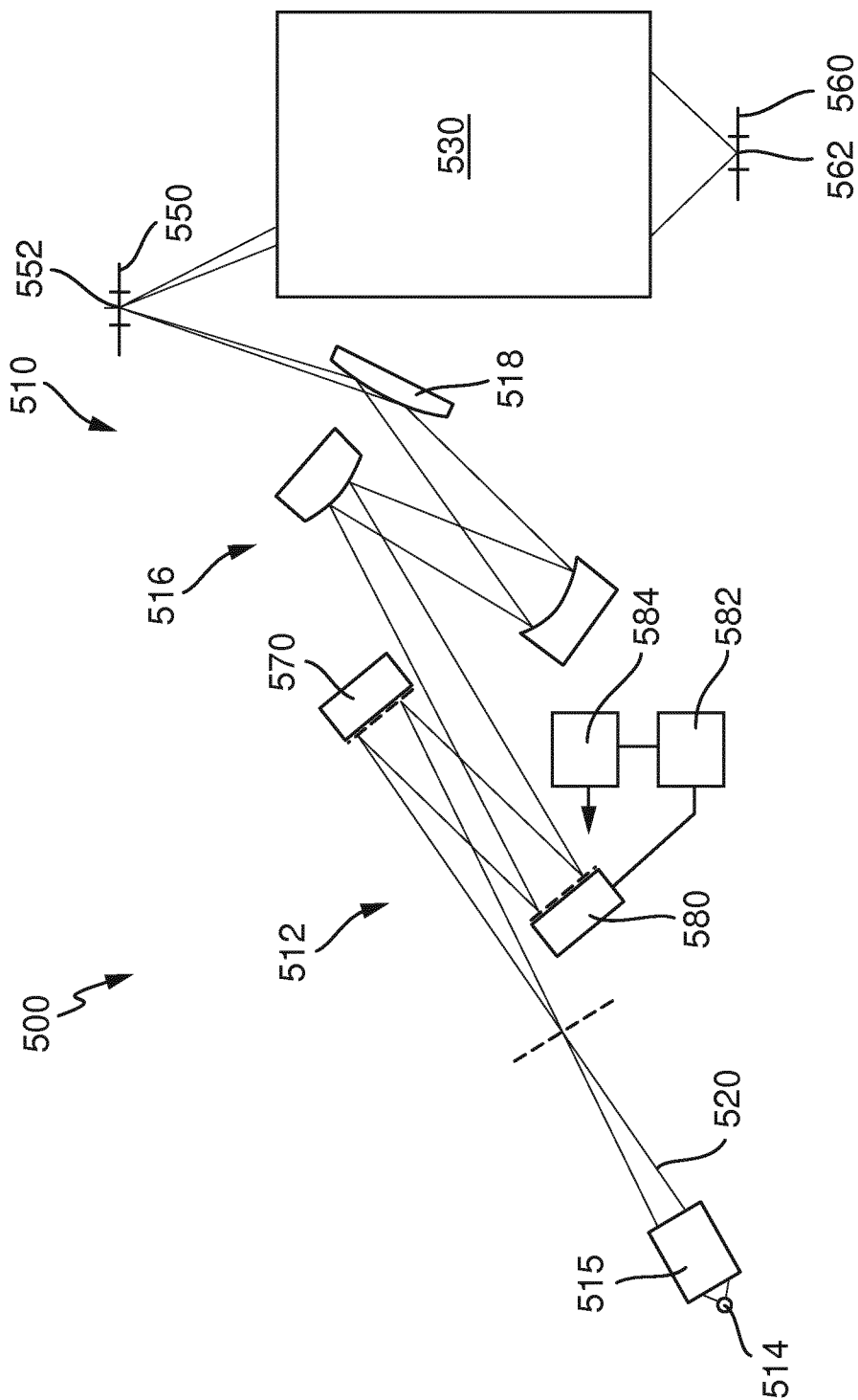


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/054572

A. CLASSIFICATION OF SUBJECT MATTER

INV. G02B7/18 G02B26/08 G03F7/20
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B81B B81C B82B B82Y G02B G03F H01L

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

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

EPO-Internal, WPI Data, COMPENDEX, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 169 464 A1 (ZEISS CARL SMT AG [DE]) 31 March 2010 (2010-03-31) the whole document paragraph [0073]; figure 9 -----	1-14
A	US 7 016 594 B1 (GODIL ASIF A [US] ET AL) 21 March 2006 (2006-03-21) abstract; figures 2, 3 column 5, line 49 - column 7, line 20 -----	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search

1 June 2012

Date of mailing of the international search report

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Heryet, Chris

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/054572

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
EP 2169464	A1	31-03-2010	EP 2169464 A1	31-03-2010
			JP 2012504324 A	16-02-2012
			KR 20110059800 A	03-06-2011
			TW 201022854 A	16-06-2010
			US 2011181850 A1	28-07-2011
			WO 2010034472 A1	01-04-2010

US 7016594	B1	21-03-2006	NONE	
