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(54) Title: METHOD FOR ILLUMINATING AN IMAGE FIELD

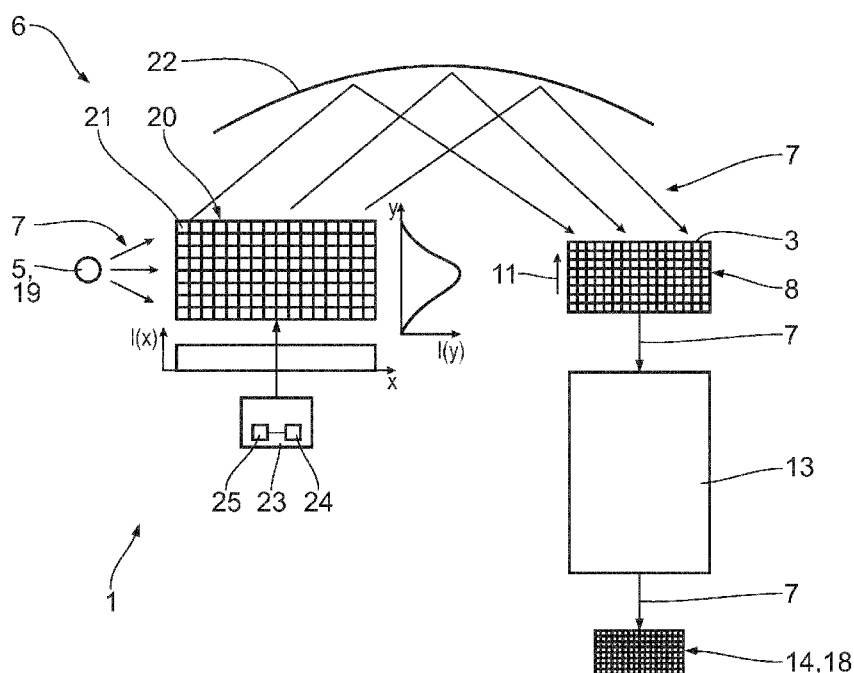


Fig. 2

(57) Abstract: The invention relates to an illumination optical system (6) for transmitting illumination radiation (7) from a radiation source (5) to an object field (3), comprising at least one mirror unit (20) with a multiplicity of individual mirrors (21) which can be displaced between different displacement positions in a controlled manner and a control device (23) for controlling the displacement of the individual mirrors (21), wherein the control device (23) is configured in such a way that predetermined exclusion positions of the individual mirrors (21) can be excluded from the displacement positions that can be set.



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Method for illuminating an image field

The content of the German patent application DE 10 2013 203 689.2 is incorporated herein by reference.

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The invention relates to an illumination optical system for transmitting illumination radiation from a radiation source to an object field. The invention furthermore relates to an illumination system and a projection exposure apparatus with such an illumination optical system. Moreover, the invention relates to a method for illuminating an image field and a method for producing a microstructured or nanostructured component.

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A microlithographic projection exposure apparatus is known from e.g. WO 2009/026947 A1.

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The invention is based on the object of further improving the illumination optical system of such a microlithographic projection exposure apparatus.

This object is achieved by the features of Claim 1.

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The core of the invention consists of providing a control device for controlling the displacement of the individual mirrors for the illumination optical system, which has at least one mirror unit with a multiplicity of displaceable individual mirrors, wherein the control device is configured in such a way that predetermined exclusion positions of the individual mirrors can be excluded from the displacement positions that can be set. In other words, it is possible to predetermine allowed and forbidden positions of the individual mirrors with the aid of the control device. As a result of this, it is possible to prevent a specific individual mirror from being displaceable into a

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displacement position which, in principle, is possible. This may be advantageous if a displacement of the individual mirror into this exclusion position would lead to an undesired effect.

- 5 In particular, with the aid of the control device, it is possible to exclude from being able to be realized beam paths which, in a targeted manner in principle, are possible.

However, it is possible to displace all individual mirrors of the mirror unit
10 into displacement positions in which they contribute to the illumination of the object field, even after predetermining the exclusion positions. In particular, it is possible to ensure that, despite predetermining the exclusion positions, there is no loss of light in the illumination optical system.

- 15 In particular, the mirror unit is a microelectromechanical system (MEMS).

According to one aspect of the invention, the mirror unit is arranged in a plane conjugate to the object field. In other words, it is arranged in a reticle-conjugated plane. However, it is also possible to arrange the mirror unit
20 at a distance from a field plane, i.e. between a field plane and a pupil plane of the illumination optical system. It is also possible to arrange a mirror unit in the vicinity of a plane conjugate to the object field and to arrange a further mirror unit at a distance from both a pupil plane and a plane conjugate to the object field. Such an arrangement, which is also referred to as
25 specular reflector, is known from e.g. WO 2004/092844 A2, which is hereby referred to and which, in its entirety, is intended to be part of the present application.

According to a further aspect of the invention, the control device comprises a memory unit for storing the exclusion positions of the individual mirrors. This is particularly advantageous if the exclusion positions can be established depending on known, fixed parameters of the optical components of the projection exposure apparatus. By way of example, properties and parameters of the optical elements of the projection optical system can be stored with the aid of the memory unit.

The memory unit can preferably be programmable. It can thereby be adapted to different conditions, for example to different properties of the projection optical system, in a particularly flexible and simple manner. In particular, it is also possible to take into account changes in the projection optical system over the service life thereof.

According to a further aspect of the invention, the control device comprises a processor, by means of which it is possible to optimize in accordance with an optimization algorithm the selection of the displacement positions of the individual mirrors for setting a specific illumination setting. As a result of this, it is possible to achieve, in particular, that the illumination of the object field and, in particular, of the image field into which the object field is imaged by means of the projection optical system, has specific criteria, in particular a specific intensity distribution and/or uniformity.

A further object of the invention consists of improving an illumination system for a projection exposure apparatus.

This object is achieved by the features of Claim 5. The advantages emerge from those described in relation to the illumination optical system.

The radiation source can be an EUV radiation source in particular. However, radiation sources for producing illumination radiation at other wavelengths are likewise feasible.

- 5 The illumination optical system may have a purely reflective, i.e. catoptric, configuration. In principle, it can also be configured in a refractive, i.e. dioptric, manner or in a mixed reflective and refractive, i.e. catadioptric, manner.
- 10 A further object of the invention consists of improving a microlithographic projection exposure apparatus. This object is achieved by the features of Claim 6. The advantages emerge from those described above.

- 15 The projection optical system of the projection exposure apparatus can also have a catoptric, dioptric or catadioptric configuration. In particular, the projection optical system can be a pure mirror lens with a plurality of projection mirrors. The projection lens can comprise in particular at least four, in particular at least six or else in particular at least eight projection mirrors.

- 20 According to one aspect of the invention, the illumination optical system can be controlled depending on parameters of the projection optical system, in particular of the optical elements thereof, in particular of the projection mirrors. In particular, it is possible to store data relating to the optical elements of the projection optical system in the memory unit of the control
- 25 device for controlling the displacement of the individual mirrors of the illumination optical system. As a result of this, it is possible, in the region of the projection optical system, to prevent illumination radiation from the radiation source to be incident on defective regions of an optical element,

in particular of a projection mirror, of the projection optical system by defining specific exclusion positions which the individual mirrors of the mirror unit of the illumination optical system cannot assume. Under real conditions, it is repeatedly the case that an optical element of the projection

5 optical system has defective regions. By way of example, scratches, contaminants, mechanical or thermal form deviations, manufacturing defects, coating deviations or effects of aging may be the reason for this. Obscurations of an optical element, in particular of a projection mirror, of the projection optical system, which may be present due to the design, are also

10 referred to as defective region or else as forbidden region. Independent of the cause of the error, it may be desirable to ensure that, where possible, no illumination radiation is incident on the defective region since this, in the most disadvantageous case, may lead not only to radiation loss but even to far more grave effects such as e.g. extraneous light or interference appear-

15 ances.

According to one aspect of the invention, all optical elements of the projection optical system, in particular all projection mirrors, are arranged in such a way that they have a normalized minimum distance P from the respective

20 closest pupil plane, where $P \geq 0.1$ applies. Here, the distance P of a component M is defined as follows: $P(M) = D(CR)/(D(SA) + D(CR))$, where $D(SA)$ is the diameter of a sub-aperture on a beam-forming surface of the component M and $D(CR)$ specifies the maximum distance from chief rays of an effective object field imaged by the lens, measured in a reference

25 plane, on the beam-forming surface of M . Therefore, $P = 0$ in a pupil plane and $P = 1$ in the field plane apply. As a result of the minimum distance P of all optical elements of the projection optical system from the in each case closest pupil plane, it is possible to ensure that a specific illumination setting, in particular a predetermined illumination pupil, can be set with the

aid of the adjustable mirror unit of the illumination optical system, even if some displacement positions are defined as exclusion positions and are therefore unable to be realized.

5 According to a further aspect of the invention, at least one mirror of the projection optical system has obscurations. In this case, the exclusion positions of the individual mirrors are preferably predetermined precisely in such a way that they correspond in each case to the position of one of these obscurations. In particular, the exclusion positions of the individual mirrors
10 are predetermined in such way that the illumination radiation reflected by an individual mirror in an exclusion position is guided at least in part to one of the obscurations after reflection on a plane defined by the object field. In particular, the illumination radiation is guided in such a way that the zero order of diffraction of the illumination radiation which proceeds
15 from an individual mirror in an exclusion position and is reflected in the object plane at least partly overlaps, in particular completely overlaps, with one of the obscurations. Optionally, the plus first/minus first order of diffraction and/or further orders of diffraction alternatively or additionally also can be taken into account.

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By predetermining the exclusion positions in this manner, it is possible to ensure that the obscurations of the optical component in the projection optical system does not lead to a substantial loss of illumination radiation in the beam path of the projection optical system.

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A further object of the invention consists of improving a method for illuminating an image field with a predetermined illumination setting.

This object is achieved by the features of Claim 10. The core of the invention consists of predetermining a number of exclusion positions when setting a predetermined illumination setting, in particular with predetermined pupil poles, which exclusion positions are excluded from the possible displacement positions of the individual mirrors of the mirror unit of the illumination optical system and thereupon determine a totality of the displacement positions of the individual mirrors for setting the predetermined illumination setting, wherein each individual mirror is to be displaced into a displacement position which deviates from all exclusion positions of this individual mirror. In general, the light spot produced by the respective individual mirror on each of the optical elements of the projection optical system has a finite, non-vanishing size. Accordingly, a plurality of exclusion positions can already correspond to a single defective region on one of the optical elements of the projection optical system.

According to one aspect of the invention, the illumination setting is built up in a scanning manner. Here, use is made of the discovery that, for a given region of the image field, all that is important is how much radiation is present at a specific point of the pupil over the whole the scanning process, i.e. how much radiation is incident on this region with a specific angle of incidence, but not at which position in the scanning direction a specific angle of incidence is present. Therefore, the whole illumination pupil is only produced for each point of the image field during the scanning process, i.e. when displacing the wafer in the image plane.

As already explained previously, the exclusion positions of the individual mirrors are predetermined dependent on parameters of the optical elements of the projection optical system according to one aspect of the invention. These exclusion positions of the individual mirrors are predetermined de-

pendent on defects of the optical elements of the projection optical system in particular.

According to a further aspect of the invention, the optical elements of the
5 projection optical system are measured in order to determine the exclusion
positions of the individual mirrors of the mirror unit of the illumination
optical system. In particular, it is possible to measure the mirrors of the
projection optical system prior to the installation thereof in the projection
optical system, in particular in order to establish defective positions. In par-
10 ticular, an interferometric method, in particular an acceptance control, can
serve for the measurement. In principle, it is also possible to measure of the
mirrors of the projection optical system in the complete system.

According to one aspect of the invention, an optimization method is pro-
15 vided in order to determine the totality of displacement positions of the
individual mirrors. What this can achieve is that the illumination of the im-
age field satisfies predetermined criteria.

In particular, the displacement positions of the individual mirrors can be
20 determined in such a way that at least 50%, in particular at least 70%, in
particular at least 90%, in particular all of the individual mirrors contribute
to the illumination of the object field. In particular, the totality of the dis-
placement positions of the individual mirrors can be determined in such a
way that there is no loss of illumination radiation in the region of the illu-
25 mination optical system despite predetermining the exclusion positions.

In particular, a mixed integer linear programming (MILP) algorithm serves
as optimization method. Here, the exclusion positions can be taken into
account as boundary conditions.

According to a further aspect of the invention, the exclusion positions of the individual mirrors are predetermined in such a way that there is at least one region on at least one optical element of the projection optical system
5 which is free from radiation independent of the illumination setting to be set.

A further object of the invention consists of improving a method for producing a microstructured or nanostructured component. This object is
10 achieved by the features of Claim 16. The advantages emerge from the descriptions above.

Further advantages, details and particulars of the invention emerge from the description of exemplary embodiments on the basis of the drawings. In
15 detail:

Fig. 1 schematically shows the configuration of a microlithographic projection exposure apparatus,

20 Fig. 2 shows a schematic illustration of the beam path in a projection exposure apparatus in accordance with Figure 1,

Fig. 3a shows an image of a mirror unit of the illumination optical system with a multiplicity of individual mirrors in a field
25 plane,

Fig. 3b shows a corresponding image in a pupil plane,

- Fig. 3c shows a corresponding image in a plane standing approximately halfway between a field plane and a pupil plane, wherein a scaled image of the mirror unit, which cannot be seen in reality, is likewise depicted,
- 5 Fig. 4a schematically shows a column of individual mirrors of the mirror unit and the pupil to be produced therewith, with $M = 4$ poles with predetermined intensities, and
- 10 Fig. 4b schematically shows the assignment of the individual mirrors to the pupil poles and the intensities of these poles emerging therefrom,
- Fig. 5 schematically shows an illustration of a mirror with obscurations in the form of passage openings,
- 15 Fig. 6 schematically shows an illustration of a further mirror with obscurations in the form of passage openings,
- 20 Fig. 7 schematically shows an illustration of a mirror with obscurations in the form of mirror elements, and
- Figs 8 to 10 show schematic illustrations of the unfolded beam path of a projection exposure apparatus with a multiplicity of optical components.
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Figure 1 shows the basic configuration of a microlithographic projection exposure apparatus 1 in a very schematic illustration. The projection exposure apparatus 1 comprises an illumination system 2 for illuminating an

- object field 3 in an object plane 4. The illumination system 2 comprises a radiation source 5 and an illumination optical system 6 for transmitting illumination radiation 7 from the radiation source 5 into the object field 3. The radiation source 5 may be provided with a collector 19 for beam forming. Arranged in the object plane 4 is a mask 8, which is also referred to as reticle, with structures 9 to be imaged. The mask 8 is mounted by a reticle mount 10. In particular, it can be displaced in a scanning direction 11 with the aid of the reticle mount 10.
- 10 A Cartesian xyz coordinate system has been plotted to simplify matters. The y-direction of same is parallel to the scanning direction 11. The object plane 4 is parallel to the x/y-plane. The z-direction is parallel to an optical axis 12 of the projection exposure apparatus 1.
- 15 Moreover, the projection exposure apparatus 1 comprises a projection optical system 13 for projecting the object field 3 into an image field 14 in an image plane 15. A wafer 18, which can be displaced in a scanning direction 17 by means of a wafer mount 16, is mounted in the image plane 15. The structures 9 of the reticle 8 are imaged on the wafer 18 with the aid of the projection optical system 13. The wafer 18 is provided with a radiation-sensitive coating, which is developed after the illumination.
- 20

While Figure 1 depicts a projection exposure apparatus 1, in which radiation passes through the reticle 8, it is likewise possible to embody the reticle 8 to be reflective and utilize it in the reflection mode. This is envisaged, in particular, if an EUV radiation source serves as radiation source 5. In this case, the projection exposure apparatus 1, in particular the illumination optical system 6 and the projection optical system 13, can have a catoptric, i.e. purely reflective, configuration. In the general case, the projection ex-

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posure apparatus 1, in particular the illumination optical system 6 and/or the projection optical system 13, can also have a dioptric or catadioptric configuration.

- 5 The projection optical system 13 comprises a plurality of projection mirrors M_i , which are numbered in order in the radiation direction, starting from the object field 3. Therefore, M_1 denotes the projection mirror which is arranged at the first position after the object field 3 in the radiation direction; M_2 denotes the second mirror, etc. The projection optical system 13
10 comprises six projection mirrors M_1 to M_6 . In general, it comprises in particular at least four, in particular at least six, in particular at least eight projection mirrors M_i .

- In respect of further details relating to the projection exposure apparatus 1
15 and the components of same, reference is made to WO 2004/092844 A2 and WO 2009/026947 A1, which are both intended to be part of the present application in their respective entirety.

- The following text describes further details of the illumination optical system 6 and of a method for illuminating the object field 3 and the image
20 field 14 with a predetermined illumination setting.

- Figure 2 once again depicts a beam path of the illumination radiation 7 in the projection exposure apparatus 1 in a very schematic manner. As clarified in an exemplary manner in Figure 2, the illumination optical system 6
25 comprises at least one mirror unit 20 with a multiplicity of individual mirrors 21. The illumination optical system 6 moreover comprises at least one further optical element 22. The at least one further optical element 22 serves for imaging the mirror unit 20 into the object field 3 in the object

plane 4, in which the reticle 8 is arranged. In particular, the imaging is size-reducing imaging.

The mirror unit 20 is configured as a microelectromechanical system (MEMS). For further details, reference is once again made to WO 2009/0269547 A1.

In particular, the mirror unit 20 comprises N_x columns and N_y rows of individual mirrors 21. The number N_y of rows is advantageously between 30 and 500, in particular between 50 and 250. A number of between 75 and 150 can be particularly advantageous.

The aspect ratio of the mirror unit 20, in particular the number $N_x : N_y$, in particular corresponds to precisely the aspect ratio of the object field and/or that of the image field. The aspect ratio is in particular greater than 4:1, in particular greater than 10:1.

In particular, the individual mirrors 21 are micromirrors, in particular with a reflection surface in the range from 10^{-10} m^2 to 10^{-4} m^2 , in particular in the range from 10^{-8} m^2 to 10^{-6} m^2 , in particular in the range from 10^{-7} m^2 to 10^{-6} m^2 .

The control device 23 comprises a processor 24, by means of which it is possible to optimize in accordance with an optimization algorithm the selection of the displacement positions of the individual mirrors 21 for setting a specific illumination setting. The method for setting a specific illumination setting will still be described in more detail in the following text.

Moreover, the control device 23 comprises a memory unit 25. It is possible to store exclusion positions of the individual mirrors 21 in the memory unit 25. Here, an exclusion position is a displacement position of an individual mirror 21 which, in principle, is a possible displacement position but
5 which, in a targeted manner, is excluded from the displacement positions that can be set. In other words, these are forbidden positions which the respective individual mirror 21 should not assume.

The memory unit 25 can preferably be programmed. It is connected to the
10 processor 24 in a data-transmitting manner.

The individual mirrors 21 can be displaced between different displacement positions in a controlled manner. The individual mirrors 21 can be displaceable in a continuous fashion. It is likewise possible to configure the
15 individual mirrors 21 to have discrete displacement positions. A control device 23 is provided in order to control the displacement of the individual mirrors 21.

In particular, the individual mirrors 21 are mounted in a pivotable manner.
20 In particular, they can have one or two degrees of freedom of pivoting. In particular, they can be pivoted about pivot axes which extend parallel to the x/y-plane. They can also be height adjustable, i.e. linearly displaceable in the z-direction.

25 In accordance with a schematic illustration in Figure 2, the individual mirrors 21 each have a square reflection surface. Here, the sides of the square reflection surface are aligned parallel with the x-direction and y-direction. However, the individual mirrors 21 preferably are rotated about an axis parallel to the z-direction in such a way that the sides thereof include an

angle in the range from $0.5 \arctan(1/N_y)$ to $2 \arctan(1/N_y)$, wherein N_y is the number of rows of individual mirrors 21 of the mirror unit 20 and the arctan function provides the arctangent of the argument thereof. In particular, the angle can be between one minute of arc and 11° , in particular between 11 minutes of arc and 3° .

The mirror unit 20 is arranged in a plane conjugate to the reticle 8. This leads to the tilt angles of the individual mirrors 21 directly corresponding to coordinates in the pupil. For a given setting of the tilt angles of all individual mirrors 21, the pupil at the reticle 8 is built up when scanning the reticle 8 in the scanning direction 11. In other words, the reticle 8 passes through the pupil when scanning in the scanning direction 11.

In particular, the displacement of the individual mirrors 21 of the mirror unit 20 can be controlled depending on parameters of the projection optical system 13.

The following text describes a method for illuminating the object field 3 and the image field 14 with a predetermined illumination setting. In order to illuminate the object field 3, the illumination radiation 7 is guided from the radiation source 5 into the object field by means of the illumination optical system 6, in particular by means of the mirror unit 20. In so doing, the mirror unit 20 is imaged in the object plane 4. By tilting the individual mirrors 21, it is possible to set the angles of incidence of the illumination radiation 7 on the reticle 8. In particular, by tilting the individual mirrors 21, it is possible to set a predetermined illumination setting, in particular a predetermined pupil, i.e. an angle of incidence distribution in the region of the reticle 8. Moreover, the uniformity of the illumination of the reticle 8 can be influenced by displacing the individual mirrors 21. Here, uniformity

is understood to mean the scan-integrated total energy at a specific field height, i.e. at a specific x-value in the reticle 8. In summary, by tilting the individual mirrors 21, it is possible to set how much radiation 7 is incident at a specific x-coordinate on the reticle 8 and from which direction of incidence it occurs.

Different angles of incidence on the reticle 8 lead to different radiation profiles in the region of the projection optical system 13. According to the invention, it was identified that it may be advantageous to exclude predetermined beam paths in the projection optical system 13. By way of example, this is desirable provided that an optical element of the projection optical system 13 has a defect, e.g. a scratch or contamination. In practical applications, such an occurrence of defects of optical elements never can be completely excluded. In particular, such defects include scratches in the surface of one of the projection mirrors M_i , contamination on same, changes in the form of same, for example due to mechanical and/or thermal stresses, manufacturing errors, deviations of the geometric and/or stoichiometric parameters of a possible layer on one of the projection mirrors M_i , and others. The proportion of the surface of the defective regions of the projection mirrors M_i may be less than 0.01, in particular less than 0.001, in particular less than 0.0001.

A local change in the reflection properties of one of the projection mirrors M_i , in particular a reduction in the reflectivity, can lead to radiation 7, which passes over this region on the relevant projection mirror, arriving at the image field 14 and hence the wafer 18 with a modified intensity. A local change in the surface form may lead to radiation 7, which passes over this region on the relevant projection mirror, arriving at the image field 14 and hence the wafer 18 with a modified optical path, i.e. the overall length

over which the radiation passes in the projection optical system 13 between the object plane 4 and the image plane 15. A modified optical path may lead to a geometric optical aberration in the image of the structures 9 situated on the reticle 8, in particular to smearing, in the image plane 15. This effect is particularly relevant if the path length change is much greater than the wavelength of the employed radiation 7. A modified optical path may lead to the radiation 7 reaching the image field 14 and hence the wafer 18 with a modified phase. This effect is particularly relevant if the wavelength change is of the order of the wavelength of the radiation 7. If the defect on the surface of one of the projection mirrors M_i has a lateral extent not much greater than the wavelength of the radiation 7, it may be that at least part of the radiation passes over a substantially different path than the intended one through the projection optical system 13 due to diffraction or other physical causes.

The image of the structures 9 situated on the reticle 8, in the image field 14 can be produced by coherent superposition of radiation 7 which has passed through the projection optical system 13 along one beam path or else along different beam paths. An intensity error of the radiation 7, which occurred along a beam path, leads to a defect of the image of the structures 9 in the image field 14. The severity of this defect depends on which portion of the radiation 7, which contributes to image forming at a point in the image field 14, has an intensity error and on the severity of the respective intensity error. The same applies analogously if there is a geometric optical aberration due to a change in the optical path length. If there is a change in the phase of the radiation 7 when reaching the image plane 15 due to a change in the optical path length, there can only be an effect if radiation 7 contributing by coherent superposition to image formation has passed through the projection optical system over various beam paths and, in the

process, has not experienced the same change in phase along all beam paths. If radiation 7 passes through the projection optical system 13 on a substantially different path than the intended one, there may be extraneous light on the wafer 18, i.e. light which also exposes the radiation-sensitive layer on the wafer at positions where no such exposure is intended.

Initially, an illumination setting to be set is predetermined. What is predetermined, in particular, is what illumination pupil, i.e. what angle of incidence, is intended to be seen at a specific field height, i.e. at a specific scanning position in the x-direction, by the wafer 18 when passing through the image field 14. By way of example, as depicted in an exemplary manner in Figures 3b and 4a and 4b, the illumination pupil comprises four pupil poles 26. In general, it comprises M pupil poles 26. In particular, frequently occurring cases are $M = 2$, $M = 4$ and $M = 8$. An annular setting can be approximated by a multi-pole with M greater than 8.

In accordance with the embodiment depicted in Figures 2 to 4 in an exemplary manner, precisely N_y individual mirrors 21 contribute to illuminating the object field 3 or the image field 14 at a given field height. However, the following deliberations can also be transferred in a simple manner to an arrangement of the individual mirrors 21 rotated with respect to the x-direction or y-direction.

By pivoting the N_y individual mirrors 21 at a given x-coordinate, the assignment thereof to the pupil poles 26 can be modified and set (see Figure 4b).

The beam paths of the illumination radiation 7 from the N_y individual mirrors 21 at a given field height x for producing a specific pupil pole 26 in

the region of the projection optical system 13 differ slightly from one another.

The number of individual mirrors 21 contributing to a given pupil pole 26 is preferably greater than 5, in particular greater than 15.

In general, the reflection surfaces of the individual mirrors 21 each have a form by means of which a plane can be tessellated. In particular, the reflection surfaces have a rectangular, triangular or hexagonal configuration.

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Therefore, a suitable assignment of the individual mirrors 21 to the pupil poles 26 can vary the precise position of the radiation 7, which contributes to a specific pupil pole 26, and thereby it is possible to optimize the imaging quality. In particular, what is possible to achieve is that no beam path falls on a defective region of an optical element in the projection optical system 13. To this end, the optical elements, in particular the projection mirrors M_i , of the projection optical system 13 are initially measured. A reflectometric and/or interferometric method serves for measuring the projection mirrors M_i .

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The points of the lens pupil O_i are thereupon calculated or estimated from the desired points of the illumination pupil P_i . This object is trivial if the structure of the reticle 8 is known. Otherwise, a structure of the reticle can be estimated in a first step from the points of the illumination pupil P_i , and the points of the lens pupil O_i then can be calculated by means of these estimated structures. In particular, estimating the structure of the reticle can be set out in such a way that the estimated structure or structures on the reticle are selected in such a way that this structure or these structures can be imaged with particularly high quality through the known illumination

pupil. In particular, lines with an orientation can be estimated as structures on the reticle. These are then imaged with particularly high quality by a specific point of the illumination pupil P_i if the azimuth of this point of the illumination pupil is rotated by 90° with respect to the direction of this line.

5 The points of the lens pupil that belong to this point of the illumination pupil then have the same azimuth as the corresponding point of the illumination pupil because the diffraction at the line then likewise occurs in this direction. If no periodicity information of such a line structure is to be estimated, it is possible to estimate a multiplicity of different lines with the

10 same orientation but different extent, i.e. period. Then, respectively one line from the center point of the illumination pupil through in each case one of the given points of the illumination pupil P_i emerges as lens pupil. A further option consists of calculating the period of a line structure for which the imaging of the structure is of particularly high quality from the

15 radial position of an illumination pupil and then of using this information as estimated structure. In the case of a point of the illumination pupil lying precisely on the edge of the NA of the illumination optical system, the estimated structure is therefore e.g. a line, the period of which is precisely the resolution limit of the projection exposure apparatus. Corresponding state-

20 ments emerge for other radial distances of a point of the illumination pupil P_i from the center point of the illumination pupil.

Tables A^i are thereupon created, wherein the entries a_{kl}^i specify whether the k -th individual mirror 21 leads to illumination at which illumination radiation

25 tion 7 overlaps with a defective region when said mirror is used for producing the illumination pupil point P_i on the i -th projection mirror M_i . This test is possible in a simple manner with the aid of the data of the lens pupil O_i and the data of the projection optical system 13. By means of ray tracing it is possible to calculate beams from each individual mirror 21 of the mirror

unit 20 to the object field 3 through the illumination optical system 6, wherein this process is repeated for each illumination pupil point P_i , i.e. for the displacement position of the individual mirror at which it contributes to illuminating the illumination pupil point P_i . After convolution with the dif-
5 fraction structure of the mask 8, one or more beams emerge, which pass through the projection optical system 13 proceeding from the mask 8. If one of these beams has a non-vanishing overlap with a region, identified as being defective, on at least one projection mirror M_i , the corresponding displacement position of the corresponding individual mirror is an exclu-
10 sion position, and the entry a_{kl}^i is set accordingly.

The tables A^i therefore contain the information relating to the exclusion positions which are intended to be excluded from the possible displacement positions of the individual mirrors 21. These exclusion positions are prede-
15 termined by means of the control device 23 before setting the tilts of the individual mirrors 21. In particular, the exclusion positions are stored in the memory unit 25.

Thereupon, a totality of displacement positions of the individual mirrors 21
20 is determined for setting the predetermined illumination setting. The method provided for this will still be explained in more detail below. When determining the displacement positions of the individual mirrors 21, each individual mirror 21 is displaced into a displacement position which deviates by a minimum value from all exclusion positions of this individual mirror
25 21. In particular, each individual mirror 21 is displaced into a displacement position in which the associated beam path in the region of the projection optical system 13 does not overlap with a beam path assigned to an exclusion position of this individual mirror 21. This can be achieved in a particularly simple manner if the individual mirrors 21 have discrete displacement

positions, the associated beam paths of which are mutually free from overlap in the projection optical system 13. In this case, and also in the general case in which the individual mirrors 21 have displacement positions, the associated beam paths of which are not without overlap in the projection
 5 optical system 13, the method, which will still be explained in more detail below, can be carried out very efficiently by means of the tables A^i and the entries a_{kl}^i thereof.

It was found that a predetermined illumination setting can also be set when
 10 predetermining exclusion positions, which are excluded from the possible displacement positions of the individual mirrors 21, and when predetermining a maximum uniformity error and/or a deviation of the actually resultant radiation intensities of the individual pupil poles 26 from predetermined intended values.

15 An optimization method is used in order to determine the totality of displacement positions of the individual mirrors 21. Here, a maximum uniformity error and/or a maximum deviation of the actually resultant radiation intensities of the individual pupil poles 26 from the predetermined intended values are initially set. In order to obtain the illumination setting with the predetermined uniformity and/or intensity of the individual pupil poles 26, the individual mirrors 21 are pivoted into predetermined displacement positions. The intensities b_i , which the individual mirrors 21 can contribute to a given pupil pole 26, are taken into account when establishing
 20 the totality of displacement positions of the individual mirrors 21.

Moreover, the displacement positions of the individual mirrors 21 are described by variables c_{ik} . Here, $c_{ik} = 1$ if the i -th little mirror is set in such a way that the associated beam path contributes to illuminating the k -th pupil pole 26 in the illumination pupil. Otherwise $c_{ik} = 0$ applies. Here, it is pos-

sible to set the i^* -th little mirror in such a way that the associated beam path does not contribute to any of the pupil poles 26, i.e. not at all to the illumination of the image field 14. In this case, $c_{i^*k} = 0$ applies for all k .

- 5 It is also possible to set each one of the individual mirrors 21 in such a way that the associated beam path contributes to illuminating the image field 14.

10 The problem of determining a totality of displacement positions of the individual mirrors 21 can be traced back to a mixed integer linear programming problem (MILP problem). There are established solution methods for solving such an MILP problem. Appropriate software packages are freely available.

- 15 The exclusion positions, i.e. the conditions of the form that the i -th individual mirror 21 may not illuminate the k -th pupil pole 26, can be implemented by means of the boundary condition(s) $c_{ik} = 0$ for given combinations i, k .

- 20 According to the invention, it was identified that, in particular, the method can be applied to projection optical systems 13, in which all projection mirrors M_i of the projection optical system 13 are arranged in such a way that they have a minimum distance P from the respectively closest pupil plane, where $P \geq 0.1$ applies. Here, the parameter P is defined as follows: $P(M) =$
 25 $D(CR)/(D(SA) + D(CR)).$

The maximum deviation of the intensities of the pupil poles 26 from predetermined intended values emerging at a specific setting of the individual mirrors 21 may be provided as a function of the maximum permissible uni-

formity error. It was identified that deviations in the intensities of the individual pupil poles 26 from the intended values are less critical than uniformity errors. The permitted maximum deviation of the intensities of the individual pupil poles 26 from the intended values may be e.g. twice as
5 large as the maximum permissible uniformity error.

In order to produce a microstructured or nanostructured component with the aid of the projection exposure apparatus 1, a predetermined illumination setting is set initially with the aid of the method explained above.
10 Thereupon, at least part of the reticle 8 in the object field 3 is imaged on a region of the light-sensitive layer on the wafer 18 in the image field 14 for the lithographic production of a microstructured or nanostructured component, in particular a semiconductor component, for example a microchip. In the process, the reticle 8 and the wafer 18 are displaced, synchronized in
15 time, in the scanning direction 17.

In the following text, a further application of the method for determining the exclusion positions for improving the optical quality of a projection exposure apparatus 1 and a corresponding projection exposure apparatus 1
20 are described.

As is known from e.g. WO 2012/041 807 A1, provision may be made for embodying the projection optical system 13 of the projection exposure apparatus 1 in such a way that one of the mirrors M_i of the projection optical
25 system 13 has obscurations 31. In particular, the correspondingly obscured projection mirror is the first M_1 or second M_2 mirror in the beam path of the projection optical system 13. For reasons of simplicity, said mirror is referred to as mirror 36 in the following text.

The obscurations 31 can be configured as passage openings 32 in a reflection surface 33 of the mirror 36. Schematic illustrations of appropriate variants of the projection mirror M_i are depicted in Figures 5 and 6 in an exemplary manner.

5

They can also be configured in the form of radiation-deflecting elements, in particular in the form of mirror elements 34 or reflection gratings. These radiation-deflecting elements can be mounted by means of web-like mounting means 35. They can be arranged in the beam path of the projection optical system 13, in particular in the region of the mirror 36, in particular by means of the mounting means 35.

10

The illustrations in Figures 5 to 7 are to be understood in a purely exemplary manner. In reality, the obscurations 31 are substantially smaller relative to the reflection surface 33. However, the number thereof can be substantially larger than depicted in Figures 5 to 7.

15

A schematic illustration of a corresponding variant of the projection mirror M_i is depicted in Figure 7 in an exemplary manner.

20

In respect of further details of the configuration of the projection mirror M_i with obscurations 31, reference is made to WO 2012/041 807 A1, which is hereby completely integrated into the present application as a constituent thereof.

25

For illustrative purposes, the mirror M_i is depicted in Figure 5 with three obscurations 31 in the form of circular radiation-transmissive regions. In Figure 6, the mirror M_i is depicted in a corresponding manner with five obscurations 31 in the form of circular radiation-transmissive regions.

Due to the underlying principles, the obscurations 31 form forbidden regions on the mirror 36. Illumination radiation 7, which impinges on one of the obscurations 31 proceeding from the reticle 8, is not guided to the wafer 18 and therefore does not contribute to an exposure of the latter.

A corresponding, obscured embodiment of the projection mirror M_i can be particularly advantageous if the reticle 8 is to be illuminated with small angles of incidence and/or a large object-side numerical aperture. In particular, it serves to be able to illuminate the reticle 8 perpendicularly. Illumination radiation 7 can be coupled into the projection optical system 13 by the obscurations 31.

In the following text, aspects of the projection exposure apparatus 1 with such an obscured mirror 36 and the application of the method for pre-determining the exclusion positions of the individual mirrors 21 are described on the basis of Figures 8 to 10.

Figure 8 schematically depicts the beam path of the illumination radiation 7, in particular the zero order of diffraction 7^0 and the first order of diffraction 7^1 of same in an unfolded illustration.

The arrangement of the optical elements depicted in Figures 8 to 10 should be understood in a purely schematic manner. It merely serves for explaining the concept according to the invention. It does not necessarily reproduce the actual arrangement of the optical elements of the illumination optical system 6 and/or of the projection optical system 13. In particular, the illumination optical system 6 and/or the projection optical system 13 can each have a catoptric, dioptric or catadioptric configuration.

Corresponding elements receive the same reference signs as in the exemplary embodiments described above, the description of which is hereby referred to.

5

In this unfolded illustration of the beam path, the obscured mirror 36 is present twice, namely once before and once after the reticle 8. Naturally, it is only present once in reality.

- 10 From an optical point of view, the two copies of the mirror 36 differ in that the regions 38 which are light-transmissive in the lens beam path are not light-transmissive in the illumination beam path. Conversely, the regions that are not light-transmissive in the lens beam path form light-transmissive regions in the illumination beam path.

15

An exemplary beam path has been plotted in Figure 8. The full line marks firstly the beam path in the illumination optical system and secondly the zero order of diffraction 7^0 of the illumination radiation 7 reflected at the reticle 8. The dashed line specifies the deviating beam path of the first order of diffraction 7^1 .

20

- There is unimpeded image forming on the wafer 18 if the illumination radiation 7 is not vignetted either in the region of the illumination optical system 6 or in the region of the projection optical system 13. In particular,
- 25 to this end, it is necessary for both the zero order of diffraction 7^0 and the first order of diffraction 7^1 to be reflected without obscurations by the mirror 36.

One or more further mirrors 37 can also be situated between the reticle 8 and the mirror 36. These can have optical power. In the case of such an optical design, the mirror 36, as seen from the reticle 8, is not the first mirror but e.g. the second mirror.

5

Figure 9 substantially corresponds to Figure 8, with an illustration of the beam path of the illumination radiation 7 being dispensed with for reasons of clarity and for a better overview. However, Figure 9 schematically depicts the position of an entry-side pupil 39 of the projection optical system 13. In the following text, this is also referred to as an illumination pupil 39. Moreover, an exit-side position of the pupil of the projection optical system 13 is depicted in Figure 9. In the following text, this is referred to as lens pupil 40.

10 To the extent that the projection optical system 13 has an intermediate image, there can be further pupil positions.

The illustration of the positions of the pupils 39, 40 in Figure 9 should likewise be understood in an exemplary manner. It does not necessarily correspond to the actual position of the pupils 39 and/or 40 in the projection exposure apparatus 1.

20 There are qualitatively different options of how the two pupils 39, 40 can lie relative to the mirror 36 or how the mirror 36 can be arranged relative to the two pupils 39, 40. These will be described in more detail in the following text.

In one variant, the mirror 36 is arranged in such a way that it is situated in the region of the entry-side pupil 39, but outside of the lens pupil 40. Here

and in the following text, an arrangement outside of a pupil is understood to mean that the mirror 36 has a distance $P \geq 0.1$ from the respective pupil.

In this case, what can be achieved by a suitable actuation of the individual mirrors 21, in particular by a suitable definition of exclusion positions of the individual mirrors 21, is that no illumination radiation 7 is lost at the mirror 36 on the path from the reticle 8 to the wafer 18. The method for illuminating the image field 14 described above, with predetermining the exclusion positions, in this case can improve the performance of the projection exposure apparatus 1 significantly.

It should be noted in this variant that a pupil pole 26 can only be present at those points in the illumination pupil 39, at which an obscuration in the form of a passage opening 32 or in the form of a mirror element 34 is situated on the mirror 36. Therefore, the setting of scan-integrated pupils is not arbitrary but restricted by the arrangement of the obscurations 31.

In accordance with a further variant, the mirror 36 is arranged both outside the entry-side pupil 39 and outside the lens pupil 40.

In this case, the method described above for illuminating the image field 14, in which exclusion positions of the individual mirrors 21 are predetermined, can be applied in a particularly advantageous manner. The inventive concept can be implemented completely in this variant. In particular, it is possible to guide the illumination radiation 7 around the obscurations 31 of the mirror 36 between the reticle 8 and the wafer 18. In contrast to the variant in which the mirror 36 is situated in the region of the entry-side pupil 39, but outside of the lens pupil 40, there are no fixed forbidden regions

in the entry-side pupil 39 or in the lens pupil 40 in this case, which originate from the mirror 36 as component of the illumination optical system 6.

Two alternatives of this variant are distinguished in the following text.

5

In accordance with the first variant, there is different defocusing in respect of the entry-side pupil 39 and the lens pupil 40. This should be understood to mean that the mirror 36 has different distances from the entry-side pupil 39 and from the lens pupil 40.

10

In this alternative, the exclusion positions of the individual mirrors 21 are defined by virtue of the fact that regions forbidden in the beam path of the illumination optical system 6 and/or of the projection optical system 13 would be incident on specific optical surfaces. The number of exclusion positions therefore increases.

15

In accordance with a second alternative, the mirror 36 is arranged in such a way that it has the same defocusing in respect of the entry-side pupil 39 and in respect of the lens pupil 40.

20

Figure 10 schematically depicts a sub-aperture 41, which is given by marginal rays 42 of a beam which, at a given point in the pupil 39 or 40, covers the whole reticle 8.

25 By a suitable design of the mirror 36, in particular by an arrangement of the obscurations 31 in such a way that no further obscuration may be present on the mirror 36 in a point-symmetric arrangement to give an obscuration 31, it is possible to ensure that whenever the illumination radiation in the beam path of the projection optical system 13 is not vignetted by the mirror

36, there is no vignetting by the mirror 36 in the beam path of the illumination optical system 6 either. This is depicted in an exemplary manner in Figure 10 by the illumination rays 43.

- 5 Thus, it suffices in this alternative to take into account the lens pupil 40 or the arrangement of the obscurations 31 of the mirror 36 in the beam path of the projection optical system 13 for the purposes of determining the exclusion positions. In particular, this simplifies the algorithmic implementation of the method for determining the exclusion positions.

Patent claims:

1. Illumination optical system (6) for transmitting illumination radiation (7) from a radiation source (5) to an object field (3), comprising:
 - a. at least one mirror unit (20) with a multiplicity of individual mirrors (21) which can be displaced between different displacement positions in a controlled manner,
 - b. a control device (23) for controlling the displacement of the individual mirrors (21),
 - c. wherein the control device (23) is configured in such a way that predetermined exclusion positions of the individual mirrors (21) can be excluded from the displacement positions that can be set.
2. Illumination optical system (6) according to Claim 1, **characterized in that** the mirror unit (20) is arranged in a plane conjugate to the object field (3).
3. Illumination optical system (6) according to one of the preceding claims, **characterized in that** the control device (23) comprises a memory unit (25) for storing the exclusion positions of the individual mirrors (21).
4. Illumination optical system (6) according to one of the preceding claims, **characterized in that** the control device (23) comprises a processor (24), by means of which it is possible to optimize in accordance with an optimization algorithm the selection of the dis-

placement positions of the individual mirrors (21) for setting a specific illumination setting.

5. Illumination system (2) for a projection exposure apparatus (1),
5 comprising
 - a. an illumination optical system (6) according to one of Claims 1 to 4 and
 - b. an radiation source (5).
- 10 6. Microlithographic projection exposure apparatus (1), comprising
 - a. an illumination optical system (6) according to one of Claims 1 to 4 and
 - b. a projection optical system (13) for projecting an object field (3) into an image field (14).
- 15 7. Projection exposure apparatus (1) according to Claim 6, **characterized in that** the displacement of the individual mirrors (21) of the mirror unit (20) of the illumination optical system (6) can be controlled depending on parameters of the projection optical system
20 (13).
8. Projection exposure apparatus (1) according to one of Claims 6 to 7, **characterized in that** all optical elements (M_i) of the projection optical system (13) are arranged in such a way that they have a minimum distance P from the respective closest pupil plane, where $P \geq 0.1$ applies, wherein the distance P of the optical elements (M_i) is in each case defined as follows: $P(M_i) = D(CR)/(D(SA) + D(CR))$, where $D(SA)$ is the diameter of a sub-aperture on a beam-forming surface of the component (M_i) and $D(CR)$ specifies the maximum
25

distance from chief rays of an effective object field (3) imaged by the lens, measured in a reference plane, on the beam-forming surface of (M).

- 5 9. Projection exposure apparatus (1) according to one of Claims 6 to 8,
characterized in that at least one mirror (36) of the projection optical system (13) has obscurations (31) and the exclusion positions of the individual mirrors (21) are predetermined dependent on these obscurations (31) in such a way that an individual mirror (21) in an
10 exclusion position would lead to a beam path in which the obscurations (31) would lead to vignetting of the beam path in the projection optical system (13).
- 15 10. Method for illuminating an image field (14) with a predetermined illumination setting, comprising the following steps:
- a. providing a projection exposure apparatus (1) according to one of Claims 6 to 9,
 - b. predetermining an illumination setting to be set,
 - c. predetermining exclusion positions, which are excluded from
20 the possible displacement positions of the individual mirrors (21),
 - d. determining a totality of the displacement positions of the individual mirrors (21) for setting the predetermined illumination setting,
 - 25 e. wherein each individual mirror (21) is to be displaced into a displacement position which deviates from all exclusion positions of this individual mirror (21).

11. Method according to Claim 10, **characterized in that** the illumination setting is built up in a scanning manner.
12. Method according to one of Claims 10 to 11, **characterized in that**
5 the exclusion positions of the individual mirrors (21) are predetermined dependent on parameters of optical elements (M_i) of the projection optical system (13).
13. Method according to one of Claims 10 to 12, **characterized in that**
10 the optical elements (M_i) of the projection optical system (13) are measured in order to determine the exclusion positions of the individual mirrors (21).
14. Method according to one of Claims 10 to 13, **characterized in that**
15 an optimization method is provided in order to determine the totality of displacement positions.
15. Method according to one of Claims 10 to 14, **characterized in that**
20 the exclusion positions are predetermined in such a way that there is at least one region on at least one optical element (M_i) of the projection optical system (13) which is free from radiation independent of the illumination setting to be set.
16. Method for producing a microstructured or nanostructured component, comprising the following steps:
25
- a. providing a microlithographic projection exposure apparatus (1) according to one of Claims 6 to 9,
 - b. providing a reticle (8),
 - c. providing a wafer (18),

- d. projecting at least part of the reticle (8) onto a region of a light-sensitive layer of the wafer (18) with the aid of the projection optical system (13) of the projection exposure apparatus (1).

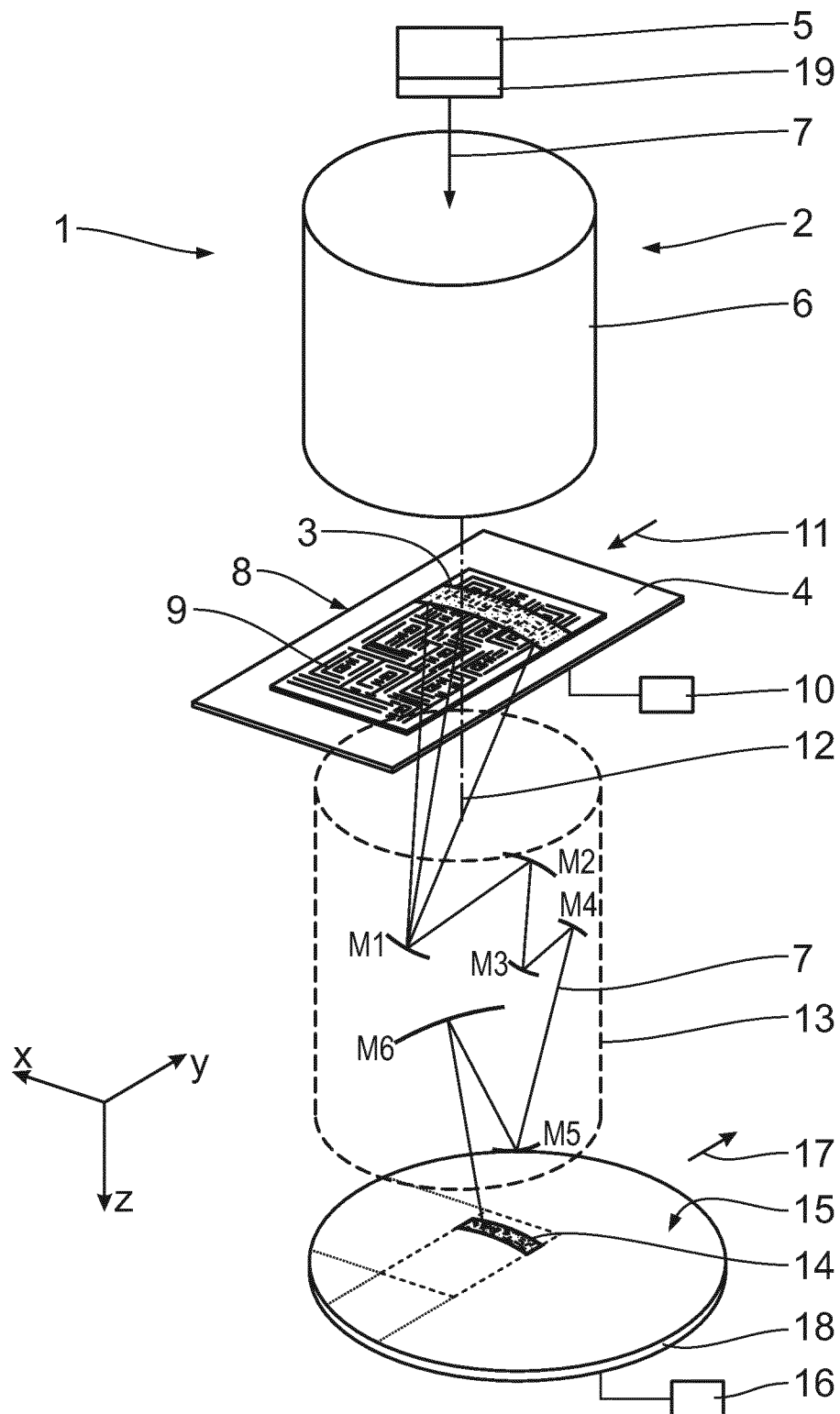


Fig. 1

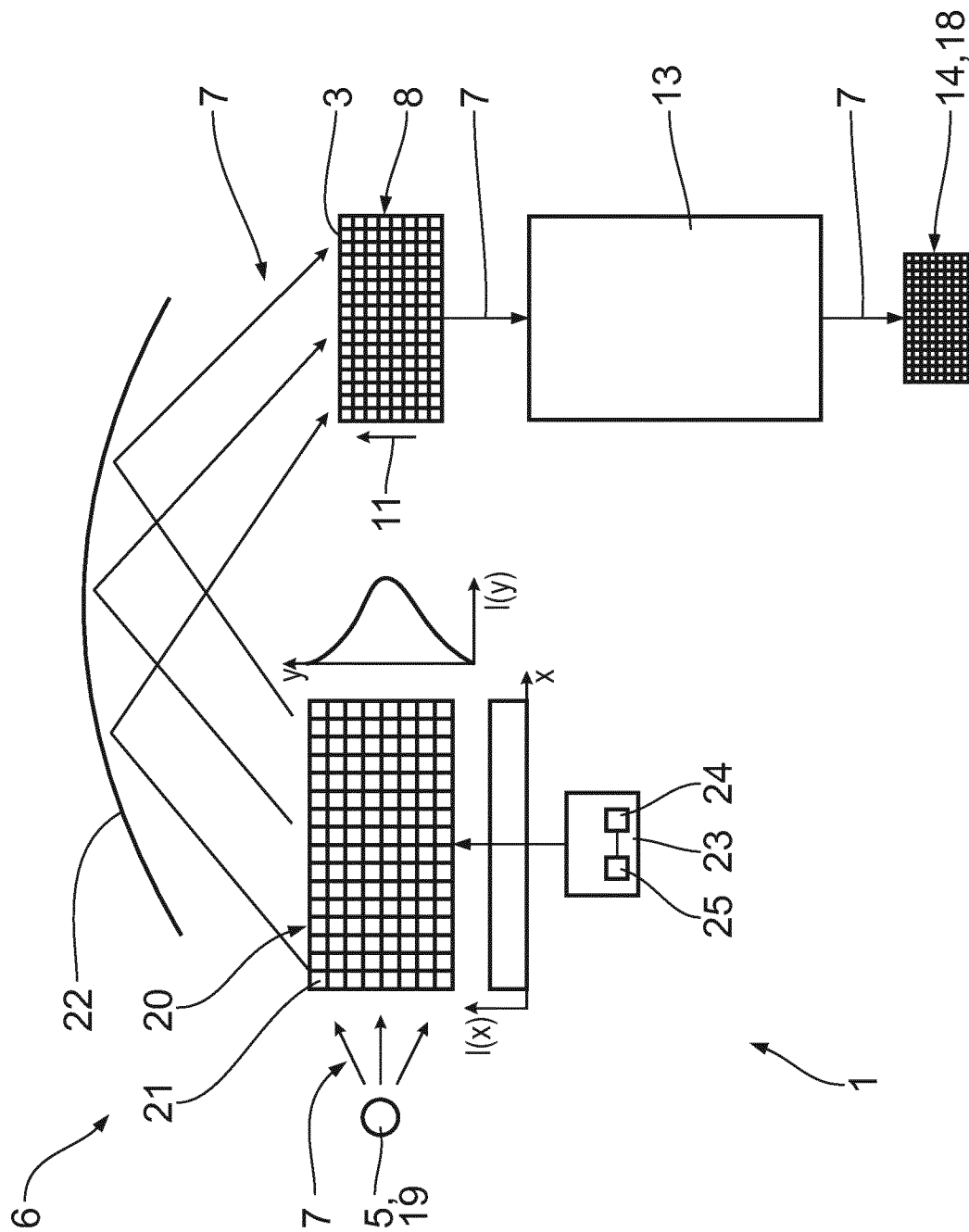


Fig. 2

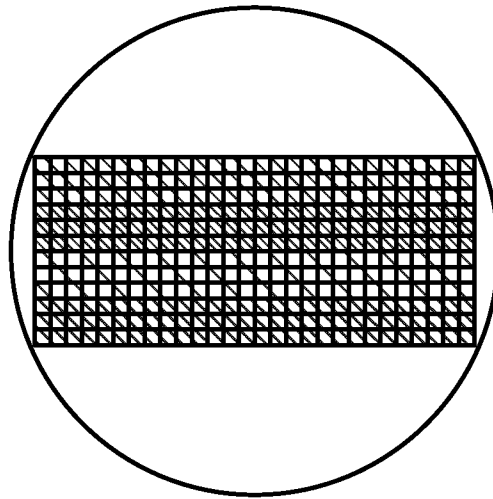


Fig. 3a

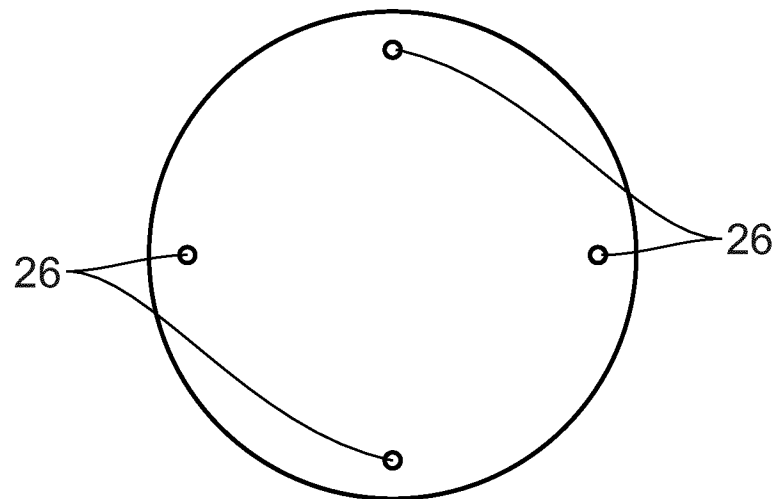


Fig. 3b

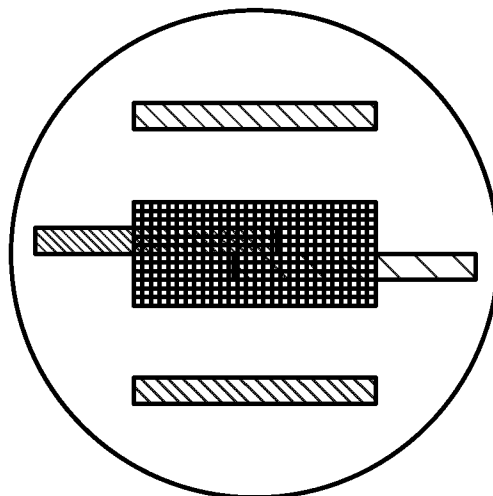


Fig. 3c

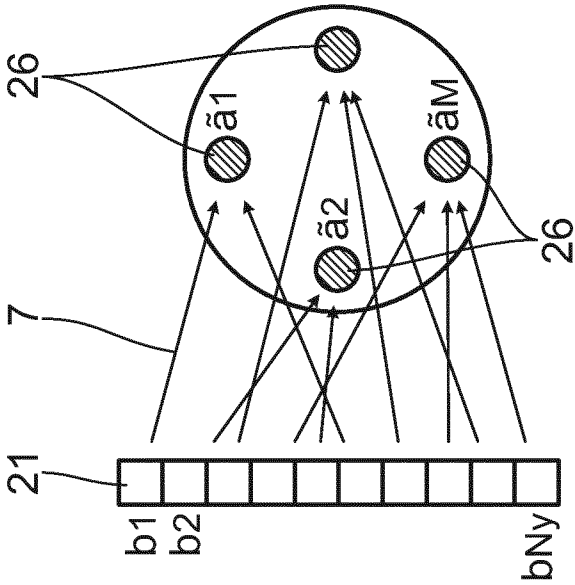


Fig. 4b

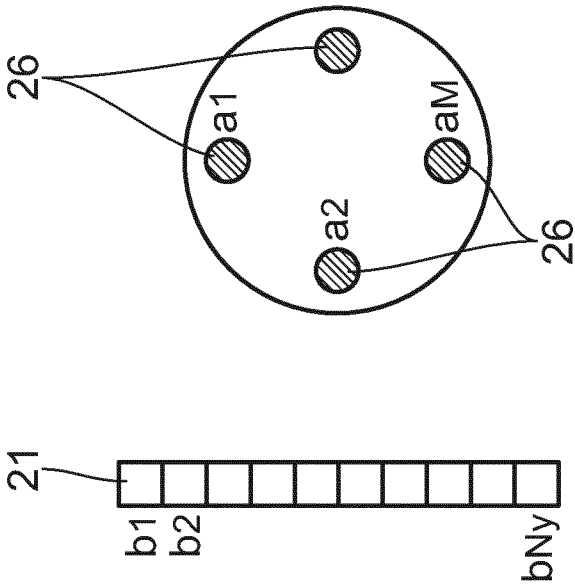


Fig. 4a

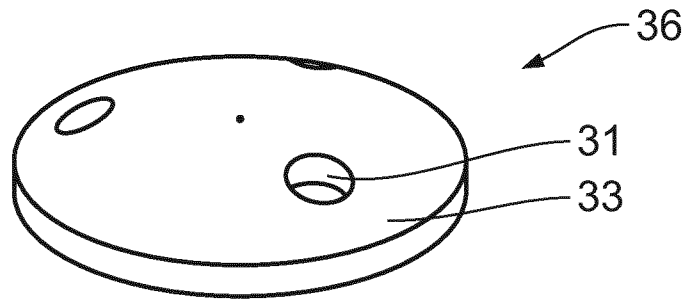


Fig. 5

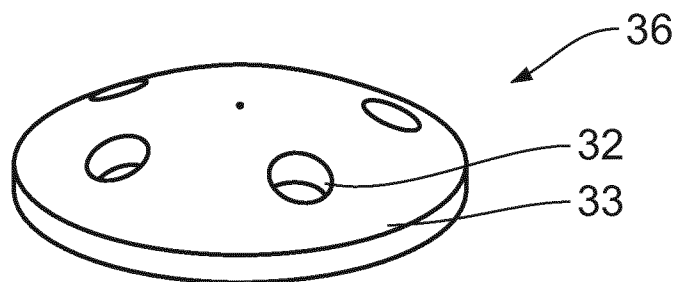


Fig. 6

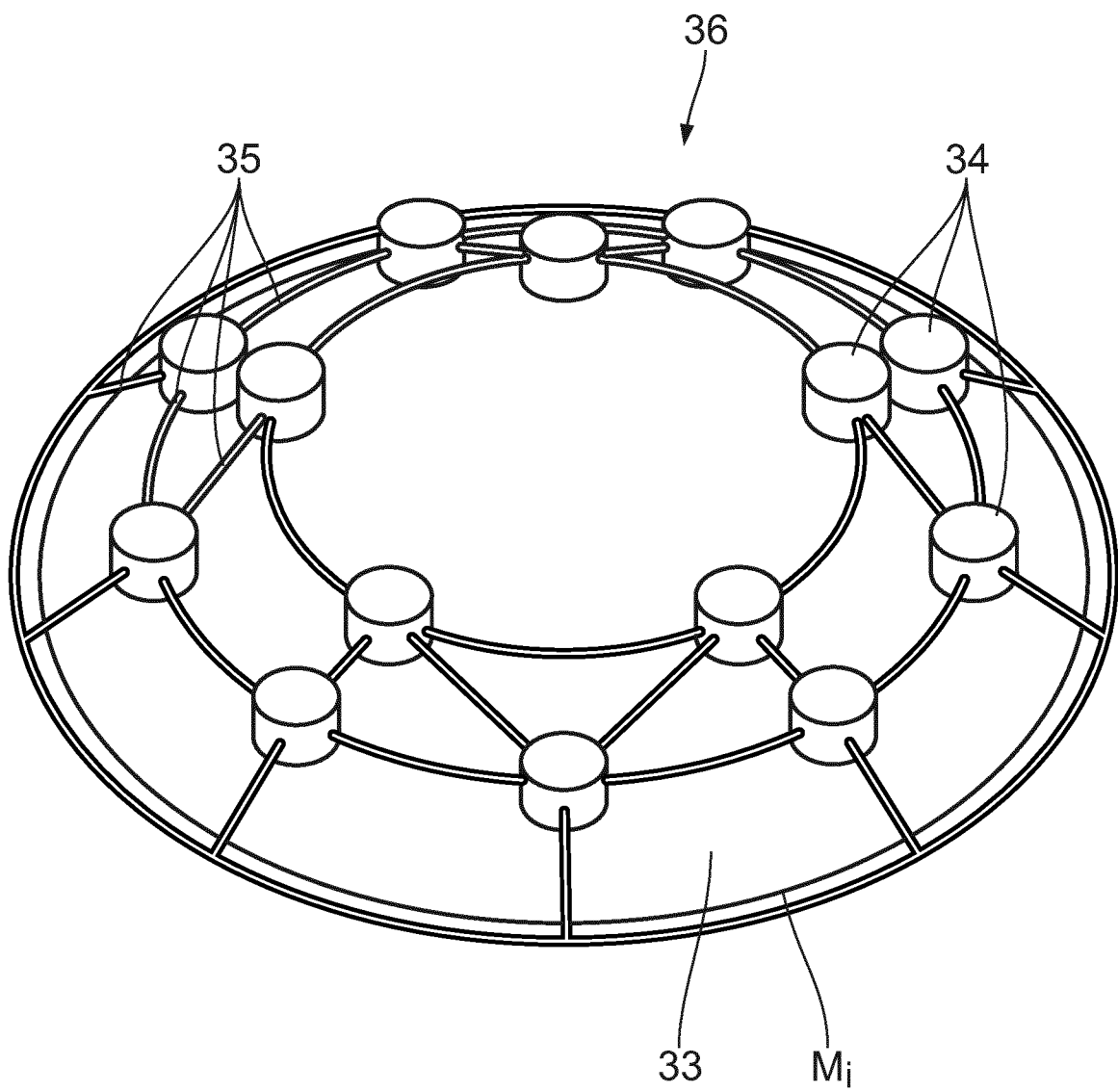


Fig. 7

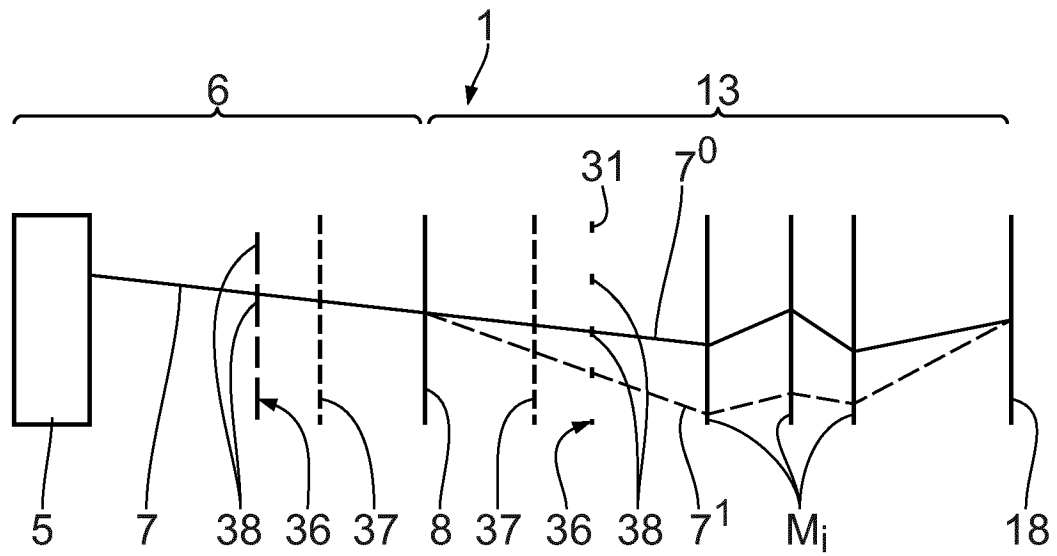


Fig. 8

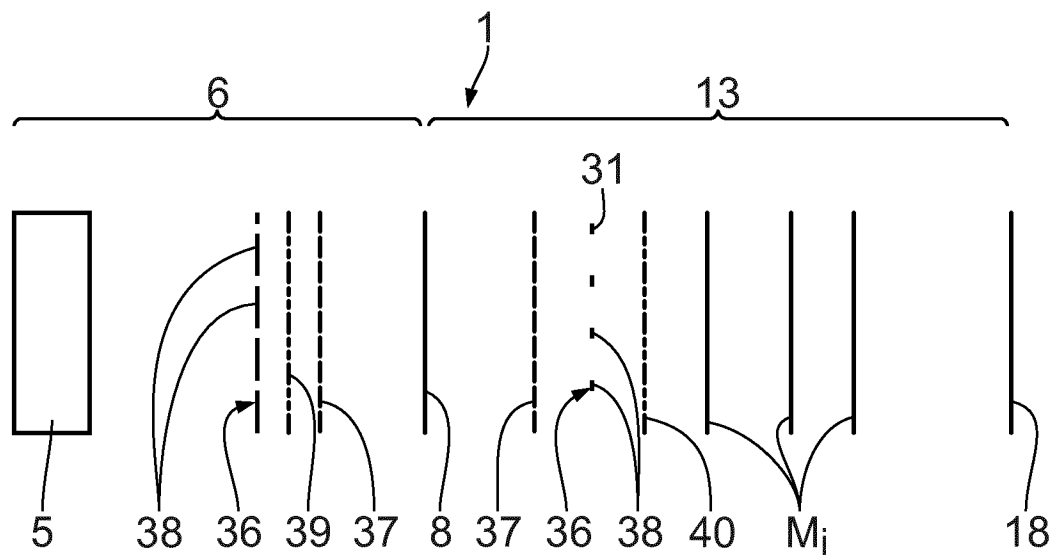


Fig. 9

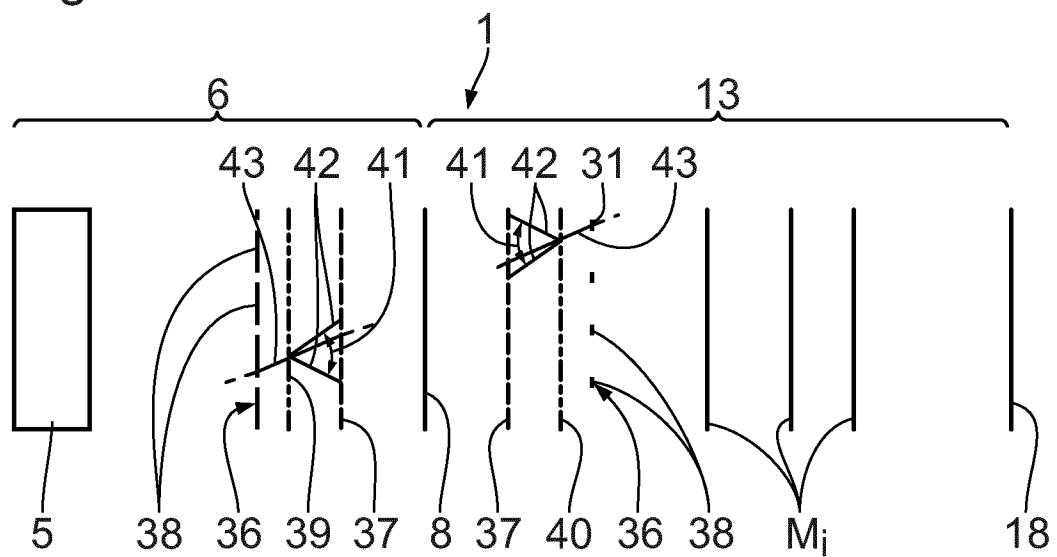


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/053917

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G03F7/20 G02B26/08
 ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G03F G02B 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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/154244 A1 (ZEISS CARL SMT GMBH [DE]; PATRA MICHAEL [DE]; DITTMANN OLAF [DE]; KIRC) 15 December 2011 (2011-12-15)	1-6,10, 11,14,16
A	page 12, line 2 - page 21, line 12; figures 1, 2, 5-7	7-9,12, 13,15
X	US 2012/154777 A1 (DE VRIES GOSSE CHARLES [NL] ET AL) 21 June 2012 (2012-06-21) paragraphs [0074] - [0082], [0159] - [0167]; figures 3, 15	1,2,4-6, 10,14,16



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

9 July 2014

Date of mailing of the international search report

18/07/2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/053917

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