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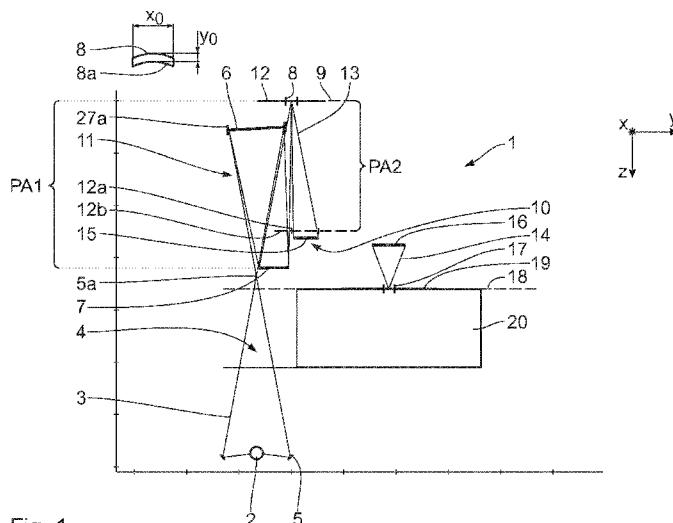
Fig. 1

(57) **Abstract**: An illumination optical assembly (1) for projection lithography serves for illuminating an object field (8), in which an object (12) to be imaged is arrangeable. The object field (8) has a scan length (y_0) along an object displacement direction (y). The illumination optical assembly has two facet mirrors (6, 7) for the reflective guidance of illumination light (3) towards the object field (8). Second facets of the second facet mirror (7) serve for guiding a respective illumination light partial beam into the object field (8). The second facet mirror (7) is at a pupil distance (PA1 + PA2) from a pupil plane (12b) of the illumination optical assembly (11) that is closest adjacent to the second facet mirror (7). The second facets are arranged in a grid, wherein at least one grid constant of the grid is predefined by the pupil distance (PA1 + PA2) and by the scan length (y_0). This results in an illumination optical assembly which achieves an illumination of predefined pupil sections that is as homogeneous as possible.

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Illumination optical assembly for projection lithography

The present application claims priority of German patent application DE 10 2014 217 610.7 the content of which is incorporated herein by reference.

The invention relates to an illumination optical assembly for projection lithography. Furthermore, the invention relates to an optical system comprising such an illumination optical assembly, an illumination system comprising such an illumination optical assembly, a projection exposure apparatus comprising such an optical system, a method for producing a micro- or nanostructured component, and a component produced by the method.

An illumination optical assembly comprising a transfer optical assembly and at least one illumination predefinition facet mirror displaced downstream is known from WO 2010/099807 A1 and US 2006/0132747 A1.

It is an object of the present invention to develop an illumination optical assembly of the type mentioned in the introduction in such a way that an illumination of predefined pupil sections of the illumination optical assembly that is as homogeneous as possible is achieved.

This object is achieved according to the invention according to a first aspect by means of an illumination optical assembly comprising the features specified in Claim 1, and according to a second aspect by means of an illumination optical assembly comprising the features specified in Claim 2.

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According to the invention, it has been recognized that a pupil illumination in accordance with the specified limit values leads to a particularly good homogenization of illuminated pupil regions of the entrance pupil. The illuminated pupil region can be impinged on overall, that is to say without

5   gaps, with a limit illumination intensity which is at least 10% of a mean illumination intensity that impinges on the pupil region. This lower limit value can also be greater than 10% and for example 20%, 30%, 40% or 50%. Insofar as gaps remain in the illuminated pupil region, which gaps are impinged on by a limit illumination intensity which is less than 10% of the

10 mean illumination intensity, then these gaps can be significantly smaller than 10% and for example 8%, 5%, 3%, 2% or 1% of the illuminated pupil region. An illumination intensity distribution of the entrance pupil which arises in a scan-integrated manner for an object to be illuminated can have pupil regions which are illuminated via more than one second facet, for

15 example via two second facets or via three second facets. This also contributes to the homogenization of the illuminated pupil regions of the entrance pupil. With the illumination optical assembly and a corresponding light source, an illumination system can arise in which, in a scan-integrated manner, a homogeneous illumination with the illumination light results

20 over the predefined pupil region to be illuminated, which deviates from a predefined value by less than a tolerance value.

An illumination optical assembly according to Claim 2 is particularly well suited to lithographic projection exposure. The advantages of this

25 illumination optical assembly correspond to those which have already been explained above. The grid constant of a facet arrangement of the second facets of the second facet mirror depending firstly on a pupil distance between the second facet mirror and the pupil plane adjacent thereto and depending secondly on a scan length, that is to say an extent of the object

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field in the object displacement direction, leads to an optimization of an illumination homogeneity in the pupil plane. A correspondingly improved object illumination is the consequence, which has a positive influence on a structure resolution during the projection exposure. In this case, the grid

5   constant of the arrangement is not strictly constant, in order to take account of optical boundary conditions on account of different spatial beam guiding geometries for the illumination light partial beams along illumination channels which are predefined via the facets of the two facet mirrors that in each case guide an illumination light partial beam. The selection of the grid

10   constants depending on the pupil distance and the scan length results in a reduction of an illumination inhomogeneity on account of a transition during the illumination of an object point on account of the displacement thereof through the object field from one illumination light partial beam to another illumination light partial beam. A homogenization is therefore

15   achieved even if an object point is illuminated by different illumination light partial beams from one and the same illumination direction during its displacement through the object field. A partial field illumination via the different illumination light partial beams is therefore not disturbing when obtaining an illumination homogeneity over the entire object field. The

20   pupil distance represents a measure of a light path between an entrance pupil arranged in the pupil plane, on the one hand, and the second facet mirror, on the other hand.

Grid arrangements according to Claims 3 to 8 have proved to be

25   particularly suitable. In the case of an arrangement according to Claim 4, a shift in particular by half the grid constant can be implemented, which leads to a particularly good homogenization. For a Cartesian grid according to Claim 6, adjacent lines can be shifted relative to one another by half a grid constant. Adjacent lines can also be shifted relative to one another for

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example by one third or by a different fraction smaller than half of the grid constants. More than one grid constant according to Claim 8 can take account of different imaging scans of a projection optical assembly that images the object field into an image field.

5

The features of the illumination optical assemblies of both aspects explained above can be combined with one another in any desired way.

The advantages of an illumination system according to Claim 9, of an

10   optical system according to Claim 10, of a projection exposure apparatus according to Claim 11, of a production method according to Claim 12 and of a micro- or nanostructured component according to Claim 13 correspond to those which have already been explained above with reference to the illumination optical assembly.

15

The component produced can be a semiconductor element, especially a microchip, in particular a memory chip.

Exemplary embodiments of the invention are explained in greater detail

20   below with reference to the drawing, in which:

Figure 1   shows highly schematically in meridional section a projection
               exposure apparatus for EUV microlithography comprising a
               light source, an illumination optical assembly and a

25   projection optical assembly;

Figure 2   shows schematically and likewise in meridional section a
               beam path of selected individual rays of illumination light
               within a pupil illumination unit of the illumination optical

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assembly according to Figure 1, proceeding from an intermediate focus through to a reticle arranged in the object plane of the projection optical assembly in the region of an illumination or object field;

5

Figure 3   shows a plan view of a transfer facet mirror of the illumination optical assembly, said mirror being arranged in a field plane;

10   Figure 4   shows an enlarged excerpt from Figure 3, which illustrates a subdivision of the transfer facet mirror into individual mirror blocks and highlights an allocation of illuminated sections on the transfer facet mirror which constitute virtual facet groups or individual mirror groups to which illumination

15   predefinition facets of a illumination predefinition facet mirror disposed downstream in the illumination optical assembly are assigned via illumination channels, wherein an x-dipole illumination setting is set via the two facet mirrors;

20   Figure 5   shows a plan view of the illumination predefinition facet mirror of the illumination optical assembly, said mirror being arranged at a distance from a pupil plane of the illumination optical assembly;

25   Figure 6   shows schematically a plan view of a scan-integrated pupil intensity distribution in the case of a y-dipole illumination setting with use of the illumination optical assembly according to Figures 1 and 2 with an illumination

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predefinition facet mirror arranged at a distance from a pupil plane of the illumination optical assembly;

Figure 7   shows schematically an excerpt from the object field which is illuminated via an illumination predefinition facet in the case of the illumination setting according to Figure 6;

Figure 8   shows an enlarged excerpt from a facet arrangement of the illumination predefinition facet mirror according to Figure 5, wherein illumination predefinition facets are arranged hexagonally;

Figure 9   shows in an enlarged view the arrangement of the illumination predefinition facets according to Figure 8, wherein the illumination predefinition facets are highlighted line by line by means of different broken lines;

Figure 10   shows an excerpt from a scan-integrated pupil intensity distribution with use of an arrangement of the illumination predefinition facets according to Figures 8 and 9;

Figure 11   shows an enlarged excerpt from a facet arrangement of a further embodiment of an illumination predefinition facet mirror, wherein illumination predefinition facets are present in a Cartesian-shifted arrangement in which the illumination predefinition facets of a line of this Cartesian arrangement are in each case shifted relative to the illumination predefinition facets about an adjacent line of this arrangement by half a grid constant of the Cartesian arrangement;

Figure 12   shows in an enlarged view the arrangement of the illumination predefinition facets according to Figure 11, wherein the illumination predefinition facets are highlighted

5   line by line by means of different broken lines;

Figure 13   shows an excerpt from a scan-integrated pupil intensity distribution with use of an arrangement of the illumination predefinition facets according to Figures 11 and 12;

10

Figure 14   shows an enlarged excerpt from a facet arrangement of a further embodiment of an illumination predefinition facet mirror, wherein illumination predefinition facets are present in a Cartesian arrangement rotated by 45° in an object

15   displacement direction;

Figure 15   shows in an enlarged view the arrangement of the illumination predefinition facets according to Figure 14, wherein the illumination predefinition facets are highlighted

20   line by line by means of different broken lines;

Figure 16   shows an excerpt from a scan-integrated pupil intensity distribution with use of an arrangement of the illumination predefinition facets according to Figures 14 and 15;

25

Figure 17   shows an enlarged excerpt from a facet arrangement of a further embodiment of an illumination predefinition facet mirror, wherein illumination predefinition facets are present

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in a Cartesian arrangement without rotation relative to an
object displacement direction; and

5   Figures 18 and 19 show examples of a Cartesian arrangement of
illumination predefinition facets of a further embodiment of
the illumination predefinition facet mirror with more than one
grid constant, namely with two grid constants.

A projection exposure apparatus 1 for microlithography that is illustrated

10   highly schematically and in meridional section in Figure 1 has a light
source 2 for illumination light 3. The light source 2 is an EUV light source
that generates light in a wavelength range of between 5 mm and 30 mm.
This can be an LPP (Laser Produced Plasma) light source, a DPP
(Discharge Produced Plasma) light source or a synchrotron-radiation-based

15   light source, for example a free electron laser (FEL).

For guiding the illumination light 3, proceeding from the light source 2, use
is made of a transfer optical assembly 4. The latter has a collector 5, which
is illustrated only with regard to its reflective effect in Figure 1, and a

20   transfer facet mirror 6, which is described in even greater detail below and
which is also designated as first facet mirror or as field facet mirror. An
intermediate focus 5a of the illumination light 3 is arranged between the
collector 5 and the transfer facet mirror 6. A numerical aperture of the
illumination light 3 in the region of the intermediate focus 5a is

25   NA = 0.182, for example. An illumination predefinition facet mirror 7,
which is also designated as second or further facet mirror and is likewise
explained in even greater detail below, is disposed downstream of the
transfer facet mirror 6 and thus the transfer optical assembly 4. The optical

components 5 to 7 are parts of an illumination optical assembly 11 of the projection exposure apparatus 1.

The transfer facet mirror 6 is arranged in a field plane of the illumination optical assembly 11.

The illumination predefinition facet mirror 7 of the illumination optical assembly 11 is arranged at a distance from pupil planes of the illumination optical assembly 11. Such an arrangement is also designated as specular reflector.

A reticle 12 is disposed downstream of the illumination predefinition facet mirror 7 in the beam path of the illumination light 3, said reticle being arranged in an object plane 9 of a downstream projection optical assembly 10 of the projection exposure apparatus 1. The projection optical assembly 10 is a projection lens. The illumination optical assembly 11 is used to illuminate an object field 8 on the reticle 12 in the object plane 9 in a defined manner. The object field 8 simultaneously constitutes an illumination field of the illumination optical assembly 11. Generally it holds true that the illumination field is formed in such a way that the object field 8 can be arranged in the illumination field.

The illumination predefinition facet mirror 7, like the transfer facet mirror 6 as well, is part of a pupil illumination unit of the illumination optical assembly 11 and serves for illuminating an entrance pupil 12a in a pupil plane 12b of the projection optical assembly 10 with the illumination light 3 with a predefined pupil intensity distribution. The entrance pupil 12a of the projection optical assembly 10 can be arranged in the illumination beam path upstream of the object field 8 or else downstream of the object

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field 8. Figure 1 shows the case in which the entrance pupil 12a is arranged in the illumination beam path downstream of the object field 8. A pupil distance PA between the second facet mirror 7 and the pupil plane 12b results in this case as the sum of a z-distance PA1 between the second facet

5   mirror 7 and the object plane 9 and the z-distance PA2 between the object plane 9 and the pupil plane 12b. It thus holds true that: PA = PA1 + PA2. The pupil distance PA is measured in the beam direction. A measure of the pupil distances is a z-coordinate firstly of the entrance pupil 12a, which is designated hereinafter as zEP, and a z-coordinate of the second facet mirror

10   7, which is designated hereinafter as zSR, in each case proceeding from the object plane 9 (z = 0).

In order to facilitate the presentation of positional relationships, a Cartesian xyz-coordinate system is used hereinafter. The x-direction runs

15   perpendicularly to the plane of the drawing into the latter in Figure 1. The y-direction runs towards the right in Figure 1. The z-direction runs downwards in Figure 1. Coordinate systems used in the drawing have x-axes running parallel to one another in each case. The course of a z-axis of said coordinate systems follows a respective principal direction of the

20   illumination light 3 within the figure respectively under consideration.

The object field 8 has an arcuate or partly circular shape and is delimited by two mutually parallel circle arcs and two straight side edges which run in the y-direction with a length y_0 and are at a distance x_0 from one another

25   in the x-direction. The aspect ratio x_0/y_0 is 13 to 1. An insert in Figure 1 shows a plan view of the object field 8, this plan view not being true to scale. A boundary shape 8a is arcuate. In an alternative and likewise possible object field 8, the boundary shape thereof is rectangular, likewise with aspect ratio x_0/y_0.

The projection optical assembly 10 is indicated only in part and highly schematically in Figure 1. An object field side numerical aperture 13 and an image field side numerical aperture 14 of the projection optical

5   assembly 10 are illustrated. Between indicated optical components 15, 16 of the projection optical assembly 10, which components can be embodied for example as mirrors that are reflective for the EUV illumination light 3, there are situated further optical components – not illustrated in Figure 1 – of the projection optical assembly 10 for guiding the illumination light 3

10   between these optical components 15, 16.

The projection optical assembly 10 images the object field 8 into an image field 17 in an image plane 18 on a wafer 19, which, like the reticle 12 as well, is carried by a holder (not illustrated in more specific detail). Both the

15   reticle holder and the wafer holder are displaceable both in the x-direction and in the y-direction by means of corresponding displacement drives. A structural space requirement of the wafer holder is illustrated as a rectangular box at 20 in Figure 1. The structural space requirement 20 is rectangular with an extent in x-, y- and z-directions that is dependent on the

20   components to be accommodated herein. The structural space requirement 20 has, for example, proceeding from the centre of the image field 17, an extension of 1 m in the x-direction and in the y-direction. In the z-direction, too, the structural space requirement 20, proceeding from the image plane 18, has an extension of 1 m, for example. The illumination light 3 has to be

25   guided in the illumination optical assembly 11 and the projection optical assembly 10 in such a way that it is in each case guided past the structural space requirement 20.

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The transfer facet mirror 6 has a multiplicity of transfer facets 21 which are also designated as first facets. The transfer facet mirror 6 can be embodied as an MEMS mirror. The transfer facets 21 are individual mirrors which are switchable at least between two tilting positions and which are

5   embodied as micromirrors. The transfer facets 21 can be embodied as micromirrors tiltable in a driven manner about two rotation axes perpendicular to one another.

From said individual mirrors or transfer facets 21, a line having a total of

10   nine transfer facets 21 is illustrated schematically in the yz-sectional view according to Figure 2, said transfer facets being indexed from left to right by 21_1 to 21_9 in Figure 2. In actual fact, the transfer facet mirror 6 has a significantly greater multiplicity of the transfer facets 21. The transfer facets 21 are grouped into a plurality of transfer facet groups not illustrated

15   in more specific detail in Figure 2 (in this respect, cf. in particular Figure 4). These transfer facet groups are also designated as individual mirror groups, virtual field facets or as virtual facet groups.

Each of the transfer facet groups guides a portion of the illumination light 3

20   via an illumination channel for partial or complete illumination of the object field 8. Via said illumination channel and an illumination light partial beam 3_i guided via the latter (cf. e.g. Figure 8), exactly one illumination predefinition facet 25 of the illumination predefinition facet mirror 7 is assigned in each case to one of the individual mirror groups or

25   transfer facet groups. In principle, each of the illumination predefinition facets 25 can for their part in turn be constructed from a plurality of individual mirrors. The illumination predefinition facets 25 are also designated hereinafter as second facets.

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For further details of possible embodiments of the transfer facet mirror 6
and the projection optical assembly 10, reference is made to
WO 2010/099 807 A.

5   At least some of the illumination predefinition facets 25 illuminate only a
partial zone or partial field of the object field 8. Said partial fields are very
individually shaped and, moreover, are dependent on the desired
illumination direction distribution (pupil shape) in the object field 8, that is
to say the illumination setting. The illumination predefinition facets 25 are
10   therefore illuminated by very different shaped virtual field facets, the shape
of which corresponds precisely to the shape of the respective partial field to
be illuminated. Moreover, each illumination predefinition facet 25
contributes to different regions of the pupil depending on the location in
the object field 8.
15

The illumination predefinition facet mirror 7 can be embodied as an
MEMS mirror, particularly if each of the illumination predefinition facets
25 is constructed from a plurality of individual mirrors. The illumination
predefinition facets 25 are micromirrors switchable between at least two
20   tilting positions. The illumination predefinition facets 25 are embodied as
micromirrors which are tiltable in a driven manner about two mutually
perpendicular tilting axes continuously and independently, that is to say
can be positioned into a multiplicity of different tilting positions.

25   One example of a predefined assignment of individual transfer facets 21 to
the illumination predefinition facets 25 is illustrated in Figure 2. The
illumination predefinition facets 25 respectively assigned to the transfer
facets 21_1 to 21_9 are indexed according to this assignment. The illumination

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predefinition facets 25 are illuminated from left to right on the basis of this assignment in the order 25_6, 25_8, 25_3, 25_4, 25_1, 25_7, 25_5, 25_2 and 25_9.

5   The indices 6, 8 and 3 of the facets 21, 25 include three illumination channels VI, VIII and III, which illuminate three object field points OF1, OF2, OF3, which are numbered from left to right in Figure 2, from a first illumination direction. The indices 4, 1 and 7 of the facets 21, 25 belong to three further illumination channels IV, I, VII, which illuminate the three object field points OF1 to OF3 from a second illumination direction. The

10   indices 5, 2 and 9 of the facets 21, 25 belong to three further illumination channels V, II, IX, which illuminate the three object field points OF1 to OF3 from a third illumination direction.

The illumination directions assigned to

15
-    the illumination channels VI, VIII, III,
-    the illumination channels IV, I, VII and
-    the illumination channels V, II, IX

20   are identical in each case. The assignment of the transfer facets 21 to the illumination predefinition facets 25 is therefore such that a telecentric illumination of the object field 8 results in the case of the illumination example illustrated pictorially.

25   The illumination of the object field 8 via the transfer facet mirror 6 and the illumination predefinition facet mirror 7 can be carried out in the manner of a specular reflector. The principle of the specular reflector is known from US 2006/0132747 A1.

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Figure 3 shows a plan view of the transfer facet mirror 6. The number of transfer facets 21 on the transfer facet mirror 6 is so great that individual transfer facets 21 are not discernible in Figure 3. The transfer facets 21 are arranged in blocks in two approximately semicircular facet regions 26, 27

5   that are illuminated with a far field 27a (cf. Figure 1) of the illumination light 3.

Figure 4 shows, in an excerpt from Figure 3, a subdivision of the transfer facet mirror 6 into a plurality of individual mirror blocks 27b each having

10   an edge contour in the form of a parallelogram. Each of the individual mirror blocks 27b has approximately 40 x 40 of the individual mirrors 21. Figure 4 furthermore highlights an allocation of the transfer facets 21 to the transfer facet groups 28, that is to say to the virtual field facets. A grouping of the transfer facets or individual mirrors 21 of the transfer facet mirror 6

15   into the transfer facet groups or individual mirror groups 28 is carried out by common tilting of said individual mirrors 21 into a predefined tilting position. The tilting positions of the individual mirrors of exactly one individual mirror group 28 are generally very similar to one another and generally differ more greatly from the tilting positions of adjacent

20   individual mirrors 21 belonging to other individual mirror groups 28. The transfer facet groups 28 are in each case imaged into the object field 8 via the illumination predefinition facet mirror 7. All transfer facets 21 of a respective one of the transfer facet groups 28 illuminate one and the same illumination predefinition facet 25.

25

The occupation of the transfer facet mirror 6 with transfer facet groups 28 according to Figure 4 is designed for an illumination pupil of the illumination optical assembly 11 with a specific illumination setting, that is

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to say for a specific, predefined intensity distribution of the illumination
light in the illumination pupil.

One example of such an illumination setting is a dipole illumination

5   setting. In a pupil plane of the illumination optical assembly 11, in the case
of such an illumination setting, two illuminated pupil regions spaced apart
from one another in a pupil coordinate $\sigma_{x/y}$ are present.

In the case of the occupation according to Figure 4, the transfer facet

10   groups 28 are predominantly rectangular.

The individual mirror groups 28 cover the far field 27a of the EUV
illumination light 3 at the location of the transfer facet mirror 6 by more
than 80%. Coverages by more than 85%, by more than 90% or even higher

15   coverages still are possible.

In Figure 4, the transfer facets 21 have the shape of parallelograms which,
like the individual mirror blocks 27b as well, are sheared perpendicular to
the scan direction. The transfer facets 21 are seated on facet carrier

20   components that form the individual mirror blocks 27b. Block interspaces
28a of said individual mirror blocks 27b can be discerned as wide white
bars without transfer facets 21 in horizontal and oblique orientation in
Figure 4. Said block interspaces 28a have a greater extent than mirror
interspaces between two individual mirrors 21 situated alongside one

25   another adjacently within one of the individual mirror blocks 27b. The
transfer facet groups 28 are identified by boundary lines having the course
of polygon progressions. Said transfer facet groups 28 usually extend
across a plurality of individual mirror blocks 27b. For the predefined

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illumination setting, the transfer facet groups 28 are predominantly almost rectangular or trapezium-shaped and have only very small gaps of unused individual mirrors 21 between adjacent transfer facet groups 28. The gaps between the individual transfer facet groups 28 are illustrated in more than

5   proportional size in Figure 4. The area proportion of said gaps in relation to the area of the entire facet carrier components is less than 10%.

The transfer facet groups 28 serve for illuminating a rectangular object field 8. The illumination predefinition facets 25 serve for the reflective,

10   superimposing guidance of partial beams of the illumination light 3 towards the object field 8. A position of the respective illumination predefinition facet 25 on the illumination predefinition facet mirror 7 predefines an illumination direction for the field points of the object field 8. An x-extension of the transfer facet groups 28 is such that the image of the

15   respective transfer facet group 28 maximally covers the entire object field 8 in the x-direction. The same correspondingly holds true for the y-extension of the transfer facet groups 28. As can be gathered from the enlarged excerpt according to Figure 4, there are many transfer facet groups 28 whose x-extension is smaller than a maximum possible x-extension, such

20   that an image of said transfer facet groups 28 in the object field 8 in the x-dimension illuminates only a part of the object field 8.

Depending on the illumination setting to be predefined by means of the illumination optical assembly 11, there exists for each illumination

25   predefinition facet 25, that is to say for each illumination channel, a maximum partial zone or partial field of the object field 8 which can be illuminated by the given illumination channel from directions that are contained in the illumination setting to be predefined. This maximum partial field size can attain the size of the entire object field 8, but in

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particular in the x-direction can also be smaller than the x-extension of the object field 8.

Figure 5 shows a plan view of the illumination predefinition facet mirror 7.

5   The illumination predefinition facets 25 are round and are arranged in hexagonal close packed fashion on a carrier (not illustrated in more specific detail) of the illumination predefinition facet mirror 7. An edge contour of this arrangement of the illumination predefinition facets 25 on the carrier of the illumination predefinition facet mirror 7 deviates from the circular

10   shape and is stadium-shaped, for example.

Figure 6 shows a typical illumination of an illumination pupil 12a of the illumination optical assembly 11, which coincides with the entrance pupil of the projection optical assembly 10, and is correspondingly arranged in

15   the pupil plane 12b in the beam path of the illumination light 3 downstream of the object field 8 (cf. Figure 1). The pupil 12a is spanned by pupil dimensions σ_x, σ_y, assigned to the object field dimensions x, y.

Figure 6 shows a y-dipole illumination setting having illumination poles

20   31, 32. A degree of filling of the pupil 12a is given by the proportion of the total area of the pupil 12a that is made up of the areas of the two illumination poles 31, 32. In this case, the area delimited by an edge 33 of the respective illumination pole 31, 32 is used as area of the respective illumination pole 31, 32. The illumination poles 31, 32 each have a

25   biconvex-lens-shaped cross section having a maximum σ_y-extension Σ_y in the region of a central σ_x-coordinate of the pupil 12a. In the region of this maximum extent Σ_y, approximately five pupil rods 34 arranged alongside one another along the σ_y-dimension, that is to say a respective rod-shaped

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illumination of the pupil 12a with the illumination light 3, contribute to the object field illumination. In a scan-integrated manner an object field point therefore "sees" the illumination light 3 from illumination directions which correspond to the position of the assigned pupil rod 34 in the pupil 12a.

5

Figure 6 illustrates a scan-integrated illumination intensity within the illumination poles 31, 32. Consideration is given here to the illumination intensity which impinges on a specific point on the reticle 12 during a scan of the reticle 12 running in the y-direction through the object field 8. The y-

10   direction is also designated as scan direction or as object displacement direction. This scan-integrated illumination intensity is distributed in the pupil 12a among pupil substructures or subpupil regions in the form of pupil rods 34 which have a larger extension in the pupil dimension σ_y than in the pupil dimension σ_x. The extension of the pupil rods 34 in the pupil

15   dimension σ_y is dependent on a difference between the reciprocal values of the z-coordinates firstly of the entrance pupil 12a and secondly of the second facet mirror 7, that is to say depending on the factor (1/zEP - 1/zSR). The variables PA1 and PA2 explained above therefore influence this factor. In addition, the extension of the pupil rods 34 in the pupil

20   dimension σ_y is dependent on the y-extension of the object field, that is to say on the scan length y_0.

Between the pupil rods 34, the illumination light 3 does not impinge on the pupil 12a, as seen from the direction of exactly one field height, that is to

25   say from the direction of exactly one x-coordinate of the object field 8. The scan-integrated illumination intensity is illustrated in Figure 6 for that pupil 12a with which an object field point is impinged on which is scanned through the object field 8 in the y-direction with a fixed x-coordinate. For

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object field points along a cross-scan direction x, this results in a migration
of the pupil rods 34 in the pupil dimension σ_x. If the pupil 12a is
considered during a hypothetical migration in the object field 8 along the x-
direction with a fixed y-coordinate, this results in a σ_x-migration of the

5   pupil rods 34, the migration speed of which is dependent firstly on the x-
migration speed in the object field 8 and secondly on the distance between
the illumination predefinition facet mirror 7 and the pupil plane. In this
case, arrangements can also be found in which such a "σ_x-migration" of the
pupil rods 34 does not take place. Insofar as such a "σ_x-migration" takes

10   place, an illumination of the object field, with regard to a σ_x-illumination
intensity distribution, is not identical for all x-object coordinates.

A σ_x-extension of the pupil rods 34 is given by a typical size of the light
source 2 or of the intermediate focus 5a. A fixed point on the reticle 12

15   "sees" in the x-direction an x-extent of secondary light sources on the
second facets 25. In the y-direction, a fixed point on the reticle 12 sees a
convolution of an extent of said secondary light sources in the y-direction
in the ideal case with a rectangular function representing a pupil migration
along the scan direction y. This size of the pupil migration in the scan

20   direction y is taken into account by means of corresponding coordination of
an arrangement of the second facets 25 such that between the resulting
pupil rods 34 the smallest possible gaps arise within desired illumination
regions of the entrance pupil 12a. The result is, in particular, a small
variation of the pupil with respect to different x-coordinates on the reticle

25   12. The effect of a migration of an intensity distribution of the illumination
light 3 in the entrance pupil 12a during the y-scanning in the x-direction is
damped or even completely suppressed on account of this homogenization
of the entrance pupil 12a.

Each of the pupil rods 34 is illuminated via precisely one illumination light illumination channel to which exactly one transfer facet group 28 and exactly one illumination predefinition facet 25 belong. A σ_x/σ_y-grid
5   arrangement of the pupil rods 34 in the pupil 12a corresponds to an x/y-grid arrangement of the illumination predefinition facets 25 on the illumination predefinition facet mirror 7.

10   In the case of the illumination of the pupil 12a according to Figure 6, apart from the pupil rods 34 near the edges 33 of the illumination poles 31, 32, all pupil rods 34 in the direction of the σ_y-coordinate are of the same length.

15   Figure 7 shows schematically a partial field 35, which is illuminated via an illumination channel of precisely one of the pupil rods 34. The object field 8 is indicated in a dash-dotted manner in Figure 7. A boundary of the partial field 35 within the object field 8 is illustrated in a dashed manner. The partial field 35 has an x-extension of x_{F1} and a y-extension of y_{F1}. The
20   following holds true:

$x_{F1} < x_0$ and $y_{F1} = y_0$. In the x-extension, therefore, the partial field 35 has a smaller extent than the object field 8. The extent of the partial field 35 in the scan direction y corresponds to the extent of the object field 8. Alternatively, the following can also hold true: $x_{F1} = x_0$ and/or $y_{F1} < y_0$.

25

Those pupil rods 34 which near the edges 33 have a smaller σ_y-extension than the other pupil rods 34 belong to illumination channels which illuminate in the object field 8 partial fields whose y-extension at least for

some sections of the illuminated partial field is smaller than the y-extension y_0 of the object field 8.

Figure 8 shows an enlarged excerpt from the hexagonal arrangement of the second facets 25 of the second facet mirror 7. This arrangement of the second facets 25 is in a hexagonal grid having a grid constant corresponding to a distance between centres of adjacent second facets 25. Since a closest hexagonal packing is involved, said grid constant is equal to an external diameter d of the circular second facets 25. The arrangement of the second facets 25 of the second facet mirror 7 is such that the grid constant is not strictly constant over the entire second facet mirror 7. Deviations of a local grid constant from a mean grid constant serve to take account of optical boundary conditions on account of different spatial beam guiding geometries for the illumination light partial beams.

The grid constant d of the hexagonal arrangement grid of the second facets 25 is predefined by the position of the second facet mirror 7, zSR, the position of the entrance pupil, zEP, and by a scan length y_0, that is to say by the y-extension of the object field 8.

The following holds true:

$$d = \frac{2|zSR|}{(n+1)\sqrt{3}} y_0 \left(\frac{1}{zEP} - \frac{1}{zSR} \right) \tag{1}$$

zEP and zSR in this case are z-coordinates of firstly the pupil plane 12b and secondly the second facet mirror 7.

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In this case, n indicates how much individual pupil rods 34 overlap one another. In the case of n = 1, pupil rods 34 that are adjacent in the y-direction with an identical x-coordinate precisely abut one another. There is then an overlap between adjacent pupil rods 34 only on account of a finite

5   extent of the light source 2. For n = 2, a respective one of the pupil rods 34 overlaps by half its respective neighbour having an identical x-coordinate in the y-direction.

Figure 9 shows the hexagonal arrangement of the second facets 25 in an

10   illustration similar to Figure 8. In Figure 9, the second facets 25 are highlighted differently line by line by means of different broken lines of their boundary. This distinction is reproduced in Figure 9 by a line-by-line type classification I, II … of the second facets 25. Overall, a distinction is drawn between four different types 25_I to 25_IV of the second facets 25.

15

Figure 10 shows, in an illustration similar to Figure 6, the scan-integrated pupil intensity distribution in the case of a predefined illumination setting. This results in pupil rods 34_I to 34_IV, which are illuminated with a respective partial beam and the illumination light 3 via the second facets

20   25_I to 25_IV. Broken lines of the pupil rod types 34_I to 34_IV correspond to the broken lines of the types 25_I to 25_IV of the second facets which are assigned thereto via the respective illumination channels.

The pupil rods 34 have an extension of dk in the σ_x-direction and an

25   extension dky in the σ_y-direction.

The pupil rods 34_I to 34_IV cover the excerpt from the entrance pupil 12a shown in Figure 10 without gaps and lead to a homogenized intensity

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distribution over this illuminated excerpt from the entrance pupil 12a. An illumination inhomogeneity on account of a transition during the illumination of an object point on account of the scan displacement thereof through the object field 8 from one illumination light partial beam,

5   assigned to one specific second facet 25, to another illumination light partial beam, assigned to another second facet 25, is thus reduced or completely avoided.

Figure 10 illustrates by way of example an extended, illuminated pupil

10   region of the entrance pupil 12a, on which the illumination light 3 impinges via a plurality of second facets 25. Within this illuminated pupil region, on account of the gap-free coverage by the pupil rods 34, an area of less than 10% of said pupil region is impinged on by a limit illumination intensity which is less than 10% of a mean illumination intensity that impinges on

15   said pupil region. In actual fact, in the illuminated pupil region according to Figure 10, the entire area of the pupil region is impinged on by an illumination intensity which is at least 10% of the mean illumination intensity and which is even significantly greater than 10% of the mean illumination intensity. In the case of alternative occupations of the

20   illuminated pupil region with the pupil rods 34, small gaps can also occur between said rods, the total area of said gaps which is illuminated with less than 10% of the mean illumination intensity being in any case less than 10% of the entire illuminated pupil region.

25   In the overlap regions between adjacent pupil rods 34, the result in a scan-integrated manner is that these pupil regions are illuminated via more than one second facet 25. In actual fact, in the case of the occupation of the illuminated pupil region of the entrance pupil 12a illustrated in Figure 10, there are overlap regions of more than two pupil rods 34, which are

correspondingly also illuminated in a scan-integrated manner via more than two second facets 25, namely via three second facets 25.

In the case of progressive shading of second facets 25 in such a way that no illumination light partial beam is guided via them in each case, pupil regions which are illuminated in a scan-integrated manner via more than one second facet, that is to say in which a plurality of pupil rods 34 overlap in a scan-integrated manner, exhibit a stepwise reduction of the scan-integrated illumination intensity, that is to say not digital behaviour in which a scan-integrated illumination intensity immediately falls to 0 within a partial region corresponding to the pupil rod 34 of the shaded second facet 25.

With the use of an EUV light source 2 for generating the illumination light partial beams 3_i, the intensity and the cross section of which on the second facets 25 vary by less than a predefined tolerance value, a homogeneous illumination over the respectively predefined pupil region or pupil section to be illuminated with the illumination light 3 results in a scan-integrated manner on account of this occupation of the section of the illumination pupil 12a with the pupil rods 34_I to 34_{IV}. This homogeneous illumination yields, over the pupil regions to be illuminated, an illumination intensity that deviates from a predefined value by less than a predefined tolerance value.

Figures 11 to 13 show, corresponding to Figures 8 to 10, the conditions with the use of a second facet mirror 7 having an alternative grid arrangement of the second facets 25. Components and functions corresponding to those which have already been explained above with reference to Figures 1 to 10, and in particular with reference to Figures 8 to

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10, bear the same reference numerals and will not be explained in detail again.

In the case of the embodiment of the second facet mirror 7 according to
5   Figures 11 to 13, the second facets 25 are arranged in a Cartesian grid, once again having a grid constant d corresponding to the external diameter of the second facets 25. Respectively adjacent lines Z_i, Z_{i+1} of the second facets 25 extending in the x-direction are shifted relative to one another by half the grid constant, that is to say by d/2. Figures 11 and 12 therefore
10   show an example of a shift of adjacent lines Z_i, Z_{i+1} of the second facets 25 in a Cartesian arrangement by a submultiple of the grid constants d relative to one another, said submultiple being 2 in this example.

Figure 12 shows analogously to Figure 9 once again a type classification of
15   the second facets 25_I to 25_{IV}, and Figure 13 shows analogously to Figure 10 a resulting illumination intensity distribution over a section of the entrance pupil 12a with correspondingly type-classified pupil rods 34_I to 34_{IV}.

For the dependence of the grid constant d of the arrangement according to
20   Figures 11 and 12 on the scan length y_0, the position of the entrance pupil 12a and the position of the second facet mirror 7, the following holds true:

$$d = \frac{|zSR|}{n+1} y_0 \left(\frac{1}{zEP} - \frac{1}{zSR} \right) \qquad (2)$$

25   Figures 14 to 16 show, corresponding to Figures 8 to 10, the conditions with the use of a second facet mirror 7 having an alternative grid arrangement of the second facets 25. Components and functions corresponding to those which have already been explained above with

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reference to Figures 1 to 13, and in particular with reference to Figures 8 to 13, bear the same reference numerals and will not be explained in detail again.

5   In the case of the embodiment according to Figures 14 to 16, the second facets 25 are arranged in a Cartesian grid, the lines and columns of which extend at an angle of 45° with respect to the object displacement direction y. This is therefore a rotated Cartesian grid having lines and columns not shifted relative to one another. Here, too, the grid constant d is equal to an

10   external diameter of the second facets 25. Rotational angles different from the rotational angle 45° in the embodiment according to Figures 14 and 15 are also possible, in particular rotational angles in the range of between 10° and 80°.

15   Figure 15 shows analogously to Figure 9 once again a type classification of the second facets 25_I to 25_{IV}, and Figure 16 shows analogously to Figure 10 a resulting illumination intensity distribution over a section of the entrance pupil 12a with correspondingly type-classified pupil rods 34_I to 34_{IV}.

20   For the dependence of the grid constant d of the arrangement according to Figures 15 and 16 on the scan length y_0, the position of the entrance pupil 12a and the position of the second facet mirror 7, the following holds true:

$$d = \frac{2|zSR|}{(n+1)\sqrt{2}} y_0 \left(\frac{1}{zEP} - \frac{1}{zSR} \right) \tag{3}$$

25

Figures 17 to 19 show further possible grid arrangements of the second facets 25 corresponding to further embodiments of the second facet mirror 7. Components and functions corresponding to those which have already

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been explained above with reference to Figures 1 to 16, and in particular to Figures 8 to 16, bear the same reference numerals and will not be discussed in detail again.

5   Figure 17 shows a non-rotated Cartesian arrangement of the second facets 25, once again having a grid constant d corresponding to an external diameter of the second facets 25. In the case of this non-rotated arrangement, the lines are aligned parallel to the x-direction and the columns are aligned parallel to the y-direction. The lines and columns of

10   the Cartesian grid therefore extend perpendicularly and parallel to the object displacement direction y. Adjacent lines are offset by half the grid constant d/2 in the x-direction with respect to one another.

Figure 18 shows one example of a Cartesian arrangement of the second

15   facets 25 having two different grid constants d_x and d_y respectively in the x- and y-directions. In this case, the grid constant d_y is equal to an external diameter of the once again round second facets 25. The grid constant d_x is 1.5 times the magnitude of the grid constant d_y. Other ratio factors d_x/d_y in the range of between 0.2 and 5 are also possible. Adjacent lines are offset

20   by half the grid constant $d_x/2$ in the x-direction with respect to one another.

The arrangement variant of the second facets 25 according to Figure 19 has the same grid constant ratio d_x/d_y as the embodiment according to Figure 18. In contrast to the embodiment in Figure 18, the second facets 25 of the

25   arrangement according to Figure 19 are embodied elliptically with the major semiaxis in the x-direction and the minor semiaxis in the y-direction. An x-extent of the elliptical second facets 25 according to Figure 19 is of exactly the same magnitude as the larger grid constant d_x. An extent of the elliptical second facets 25 in the y-direction is equal to the grid constant d_y.

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Adjacent lines are offset by half the grid constant $d_x/2$ in the x-direction with respect to one another.

5   During the configuration of the illumination optical assembly 11, firstly the design of the illumination optical assembly 11 including the object field dimensions, in particular the scan length y_0 and the pupil distance PA between the second facet mirror 7 and the entrance pupil 12a, is predefined. Proceeding therefrom, a grid type of the arrangement of the
10   second facets 25 of the second facet mirror 7 is chosen, wherein here aspects with regard to the integration of the tilting actuators and also thermal aspects may be of importance. Finally, the at least one grid constant d of the chosen grid arrangement is calculated in accordance with the above equations and the second facet mirror 7 is configured with
15   second facets 25 in accordance with the size and grid arrangement.

In order to produce a microstructured component, in particular a highly integrated semiconductor component, for example a memory chip, with the aid of the projection exposure apparatus 1, firstly the reticle 12 and the
20   wafer 19 are provided. Afterwards, a structure on the reticle 12 is projected onto a light-sensitive layer on the wafer 19 by means of the projection optical assembly of the projection exposure apparatus 1. By means of the development of the light-sensitive layer, then a microstructure is produced on the wafer 19 and the micro- or nanostructured component is produced
25   therefrom.

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Patent Claims

1. Illumination optical assembly as part of an illumination system for
    projection lithography for illuminating an object field (8), in which an
    object (12) to be imaged is arrangeable, which is displaced during a
    projection exposure in an object displacement direction (y) through the
    object field (8),

    -   comprising a first facet mirror (6) having first facets (21) for the
        reflective guidance of illumination light (3),

    -   comprising a second facet mirror (7) for the reflective guidance of
        the illumination light (3) reflected by the first facet mirror (6)
        towards the object field (8),

    -   wherein the second facet mirror (7) has second facets (25) for
        guiding a respective illumination light partial beam (3_i) into the
        object field (8),

    -   wherein the second facet mirror (7) is at a distance from a pupil
        plane (12b) of the illumination optical assembly (11),

    -   wherein the illumination optical assembly (11) is embodied such
        that with the use of an EUV light source (2) for generating the
        illumination light partial beams (3_i) an entrance pupil (12a) in the
        pupil plane (12b) has at least one extended, illuminated pupil
        region on which the illumination light (3) impinges via a plurality
        of second facets (25), wherein within the illuminated pupil region
        an area of less than 10% of said pupil region is impinged on by a
        limit illumination intensity which is less than 10% of a mean
        illumination intensity that impinges on the pupil region.

2. Illumination optical assembly (11) for projection lithography for
    illuminating an object field (8), in which an object (12) to be imaged is

arrangeable, which is displaced during a projection exposure in an object displacement direction (y) through the object field (8), wherein the object field (8) has a scan length (y_0) along the object displacement direction (y),

5
- comprising a first facet mirror (6) having first facets (21) for the reflective guidance of illumination light (3),

- comprising a second facet mirror (7) for the reflective guidance of the illumination light (3) reflected by the first facet mirror (6) towards the object field (8),

10
- wherein the second facet mirror (7) has second facets (25) for guiding a respective illumination light partial beam (3_i) into the object field (8),

- wherein the second facet mirror (7) is at a pupil distance (PA) from a pupil plane (12b) of the illumination optical assembly (11) that is
15
closest adjacent to the second facet mirror (7),

characterized in that

the second facets (25) are arranged in a grid, wherein at least one grid constant (d; d_x, d_y) of the grid is predefined by the pupil distance (PA) and by the scan length (y_0).

20
3. Illumination optical assembly according to Claim 2, **characterized in that** the second facets (25) are arranged in a Cartesian grid, the lines (Z) and columns of which extend perpendicularly (x) and parallel (y) to the object displacement direction.

25
4. Illumination optical assembly according to Claim 3, **characterized in that** respectively adjacent lines of the second facets (25) which extend perpendicularly (x) to the object displacement direction (y) are shifted relative to one another by a submultiple of the grid constants (d).

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5.   Illumination optical assembly according to Claim 2, **characterized in that** the second facets (25) are arranged in a hexagonal grid.

6.   Illumination optical assembly according to Claim 2, **characterized in that** the second facets (25) are arranged in a Cartesian grid, the lines and columns of which extend at an angle of between 10° and 80° with respect to the object displacement direction (y).

7.   Illumination optical assembly according to Claim 6, **characterized in that** the second facets (25) are arranged in a Cartesian grid, the lines and columns of which extend at an angle of 45° with respect to the object displacement direction (y).

8.   Illumination optical assembly according to any of Claims 2 to 7, **characterized in that** the grid has more than one grid constant (d_x, d_y).

9.   Illumination system comprising an illumination optical assembly according to any of Claims 1 to 8 and a light source (2).

10. Optical system comprising an illumination optical assembly according to any of Claims 1 to 8 and a projection optical assembly (10) for imaging the object field (8) into an image field (17).

11. Projection exposure apparatus comprising an optical system according to Claim 10 and a light source (2).

12. Method for producing a microstructured component comprising the following method steps:

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- providing a reticle (12),
- providing a wafer (19) having a coating that is sensitive to the illumination light (3),
- projecting at least one section of the reticle (12) onto the wafer

5   (19) with the aid of the projection exposure apparatus (1) according to Claim 11,

- developing the light-sensitive layer exposed with the illumination light (3) on the wafer (19).

10   13. Component, produced according to a method according to Claim 12.
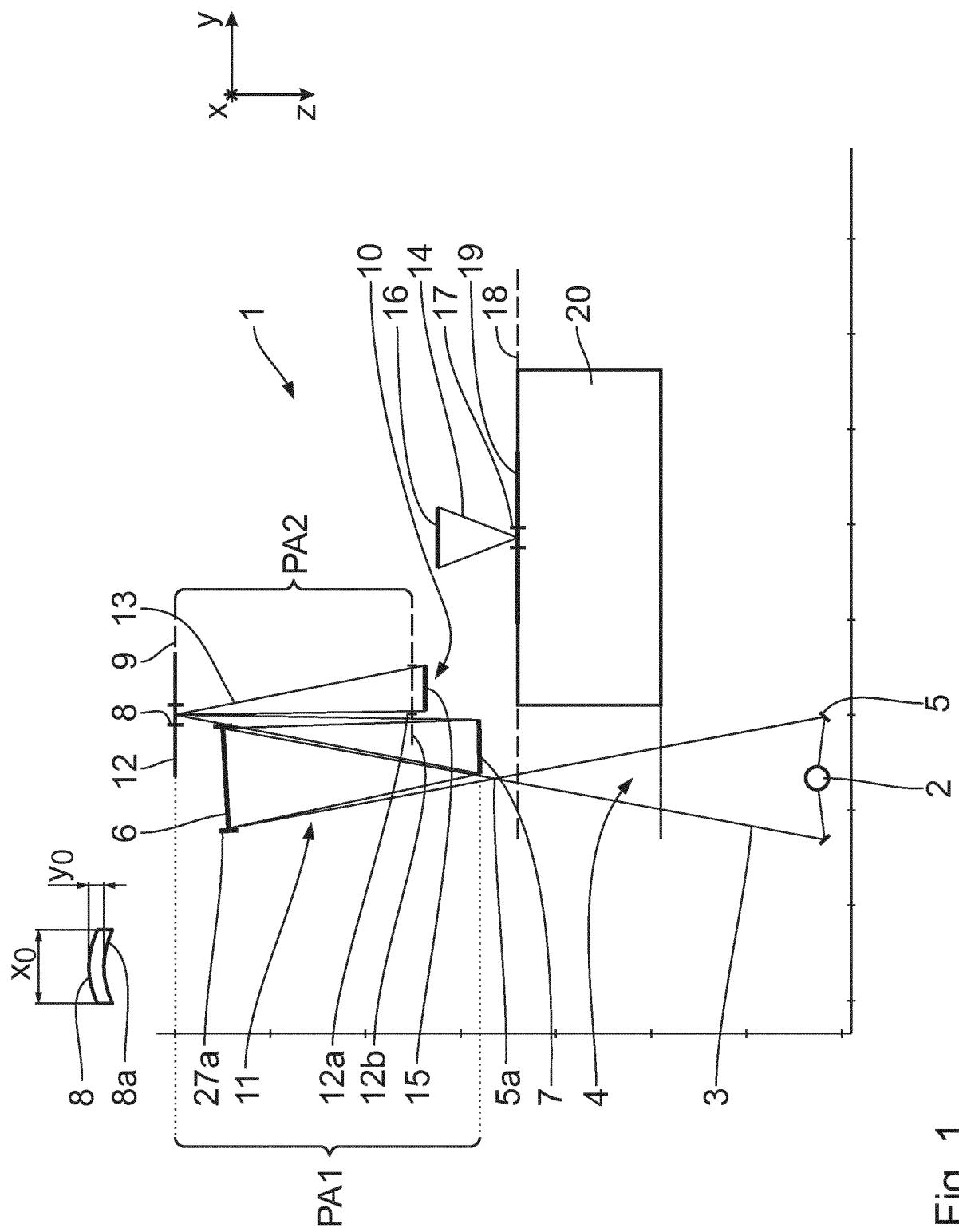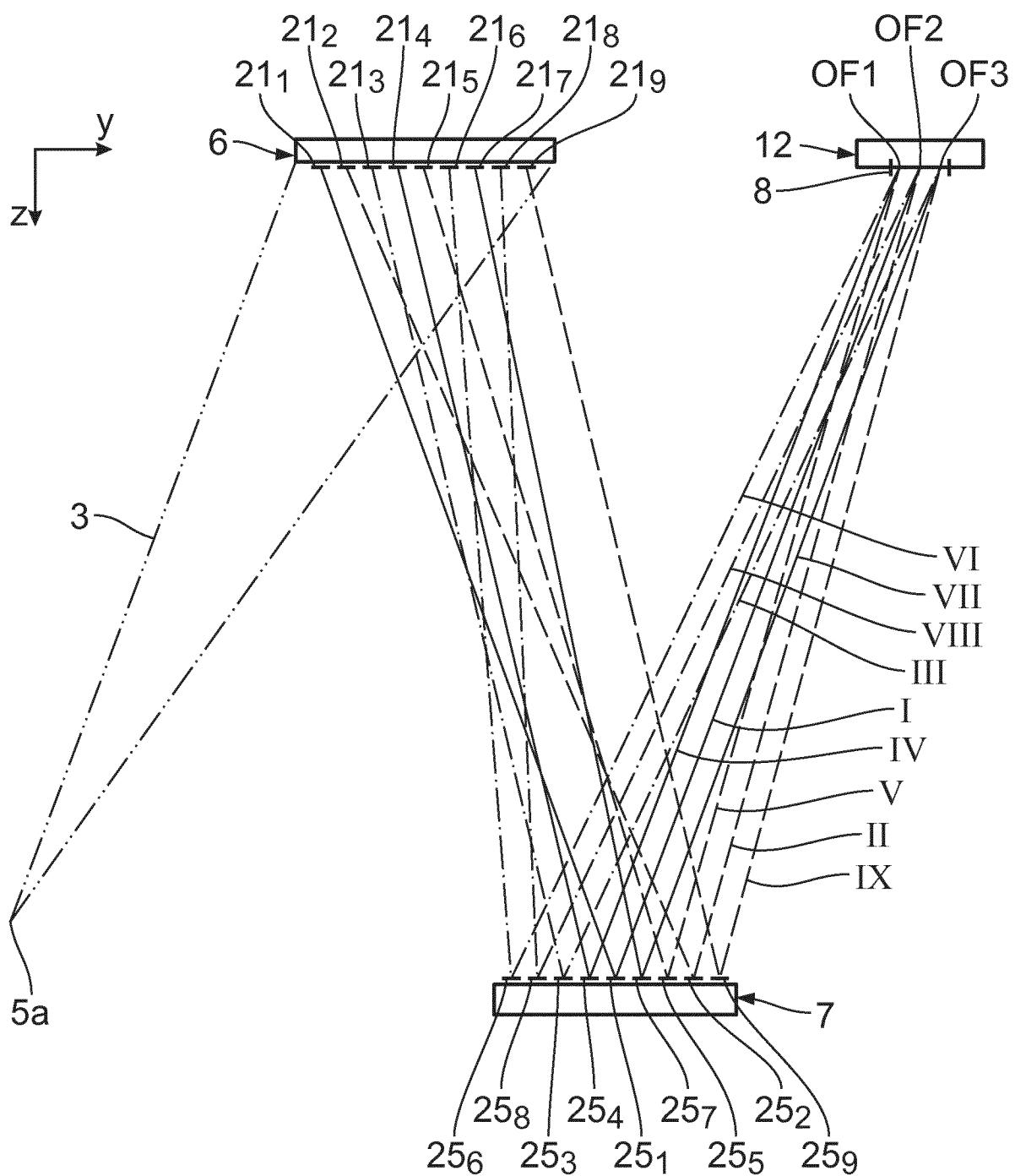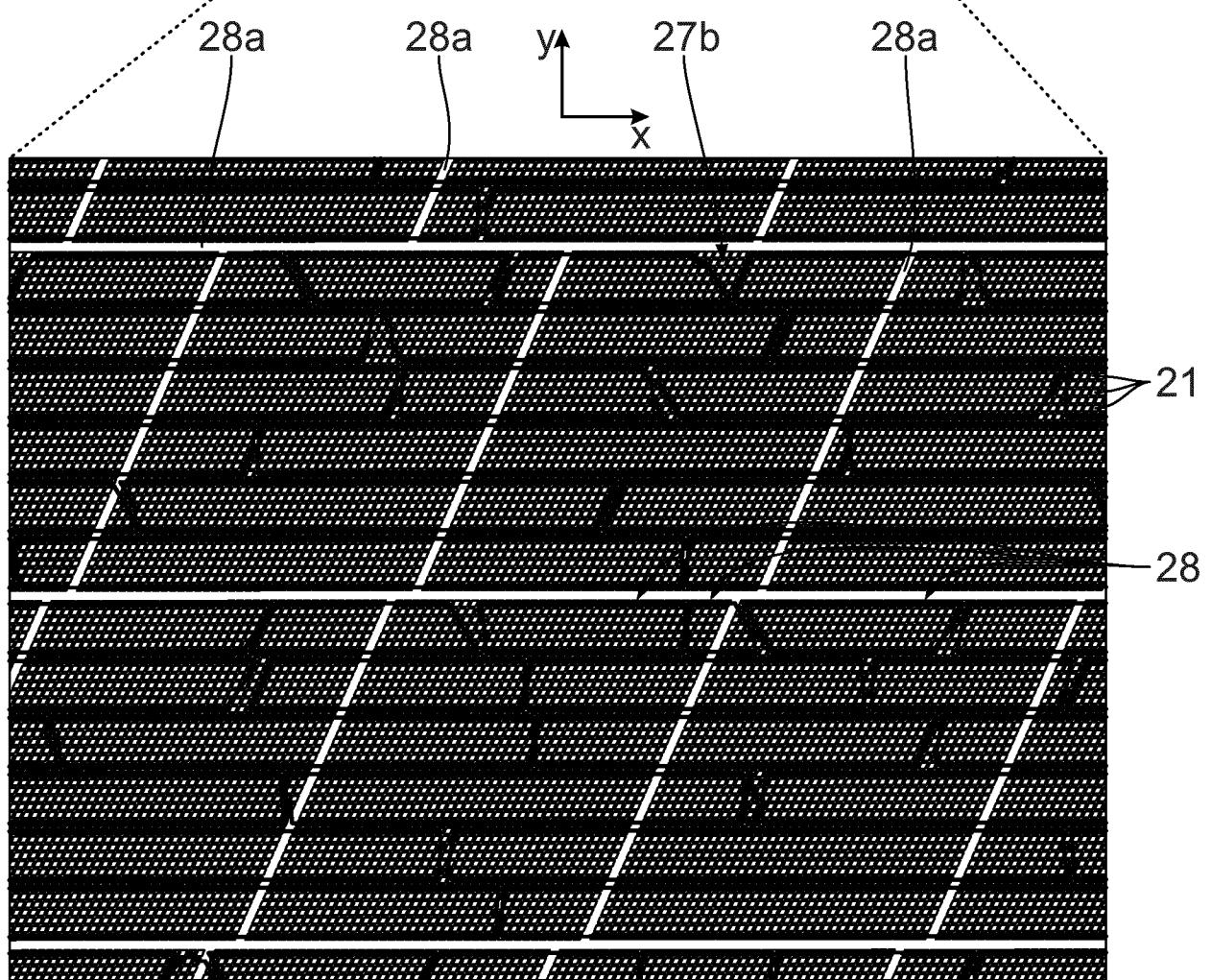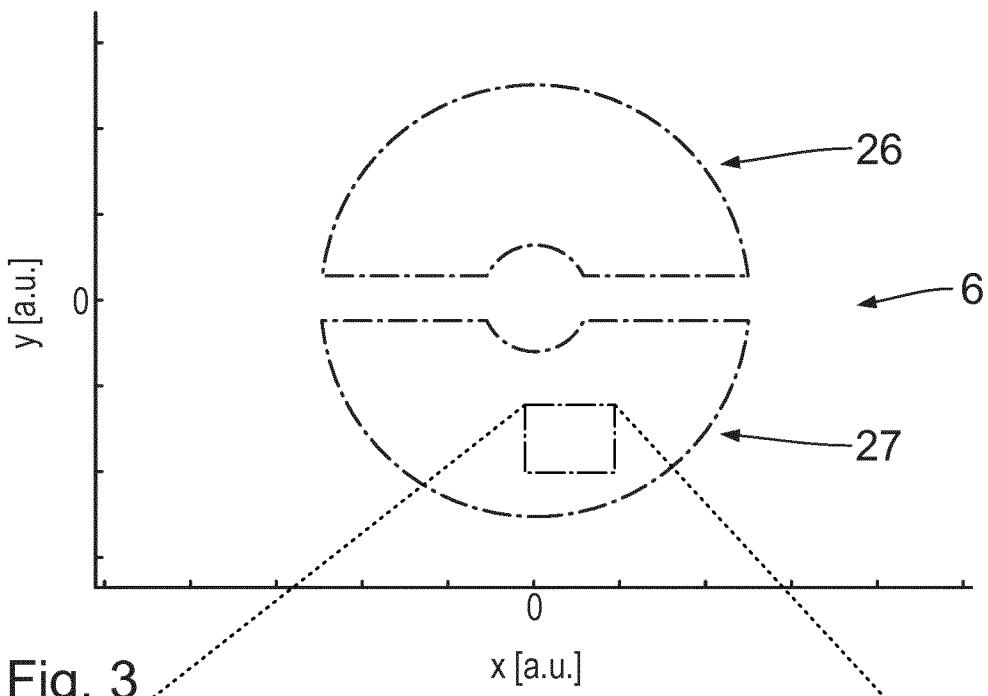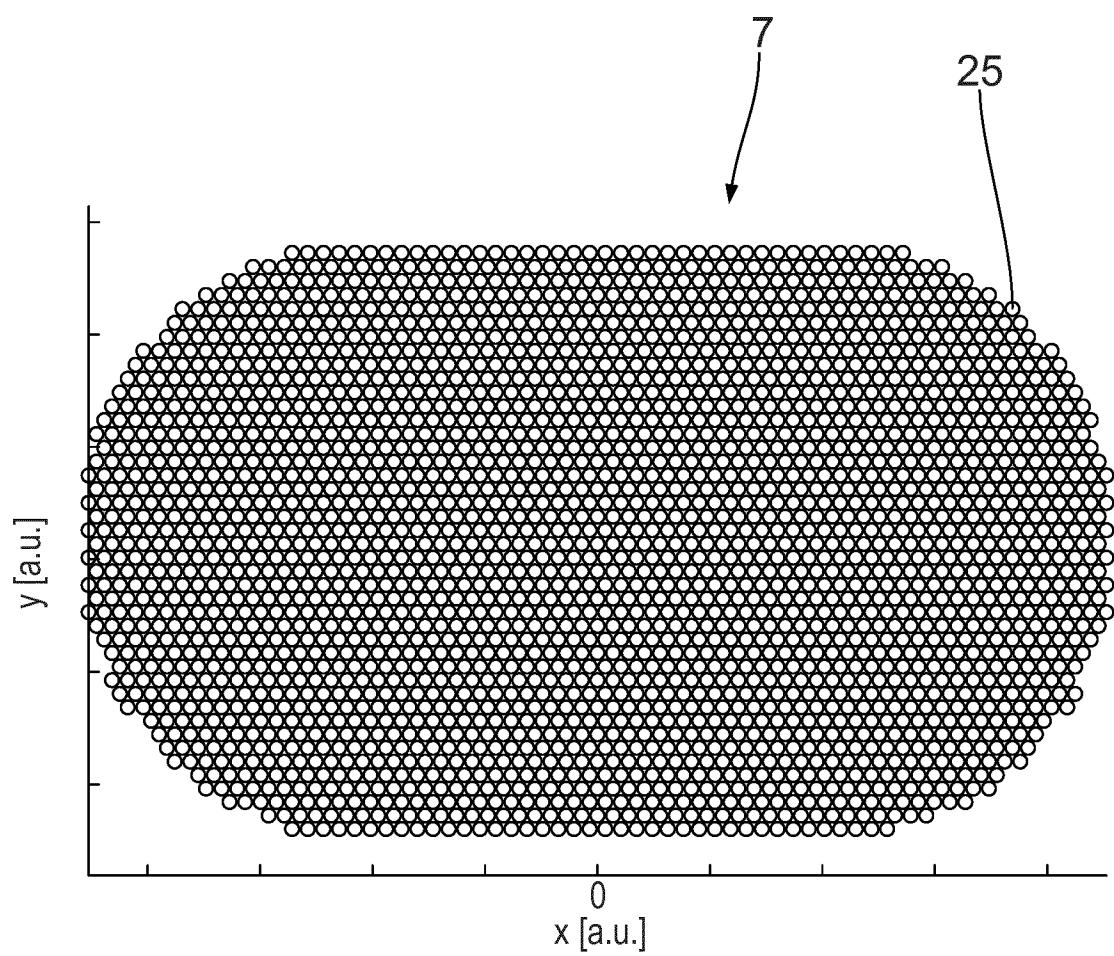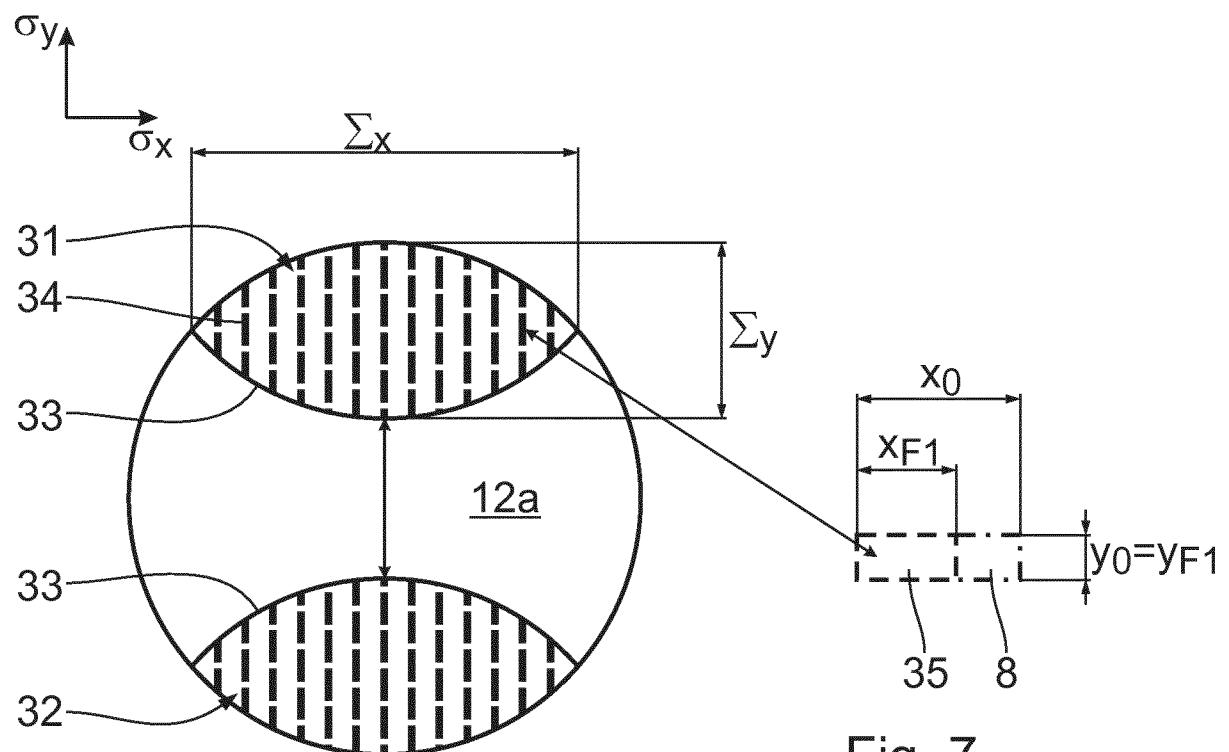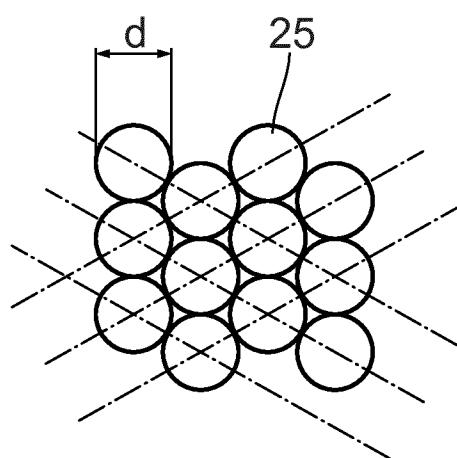
Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

25III

25II

25I

d

25IV

25III
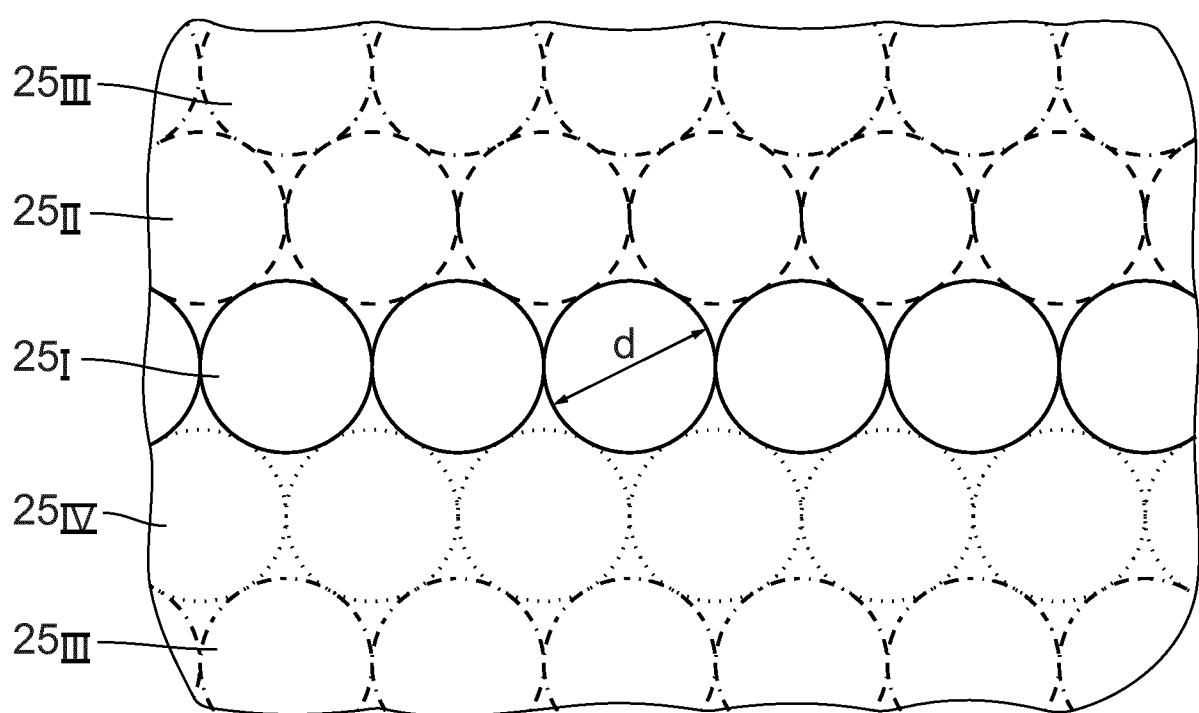
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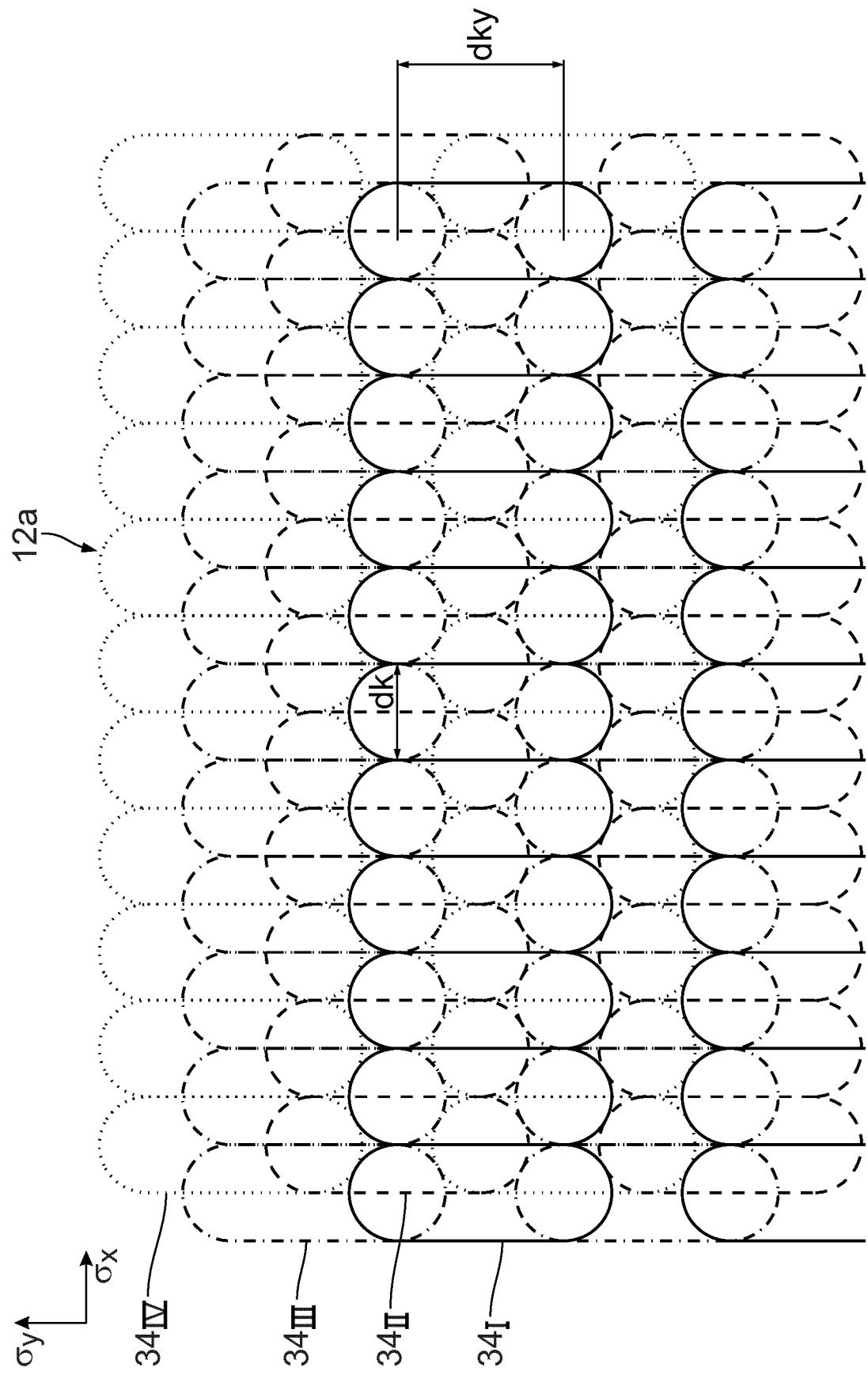
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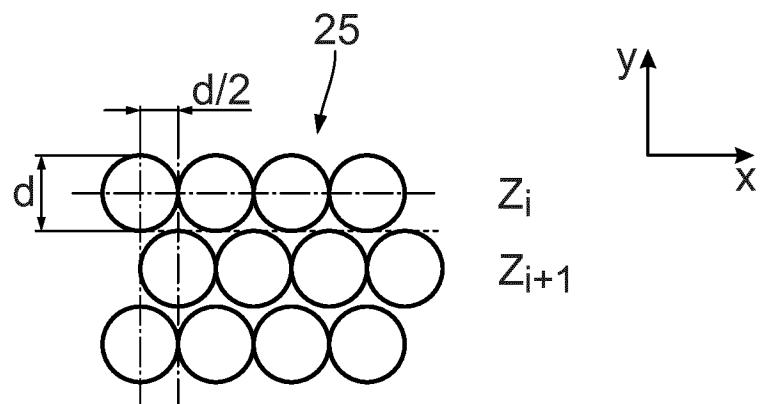
Fig. 11
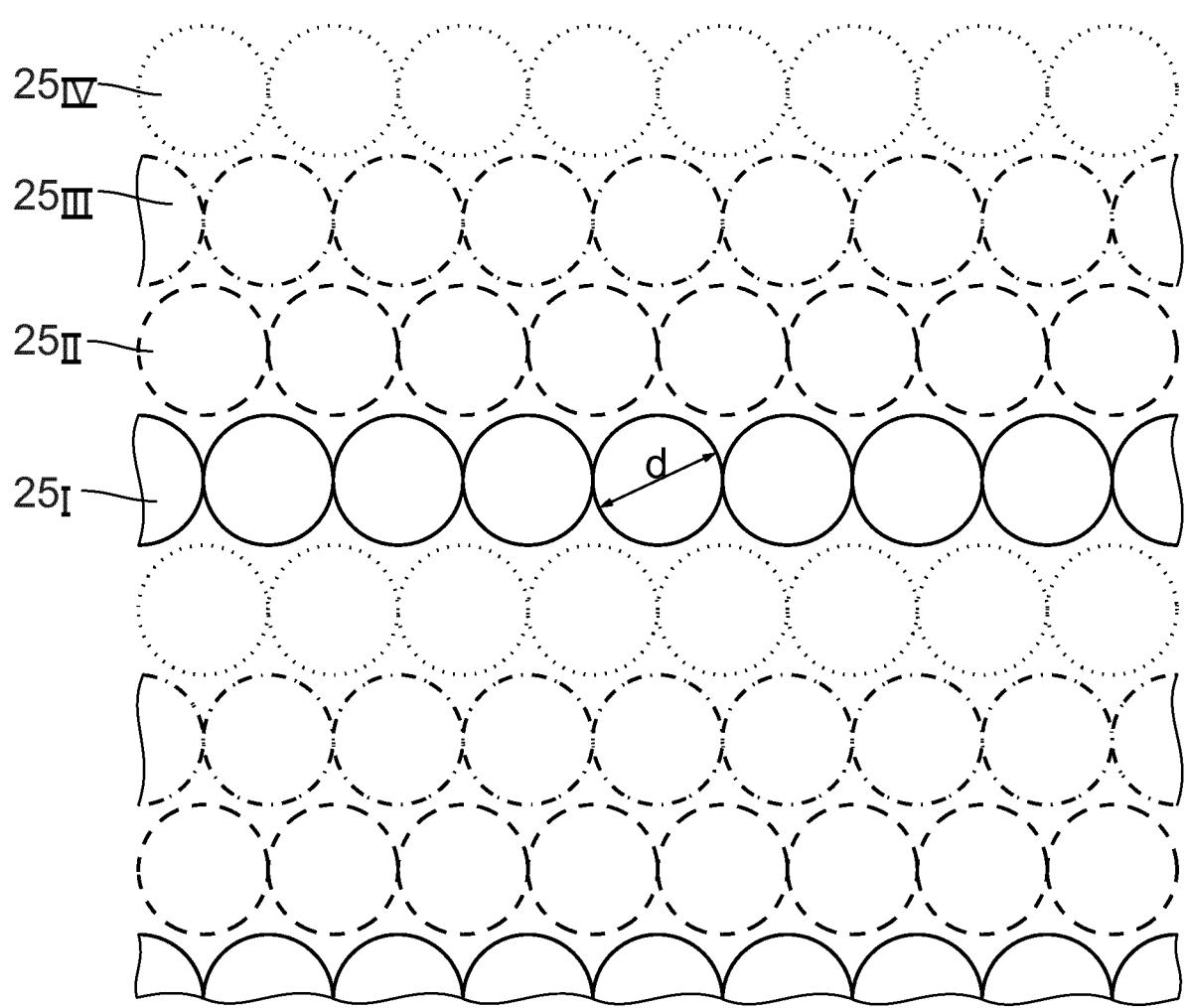
Fig. 12
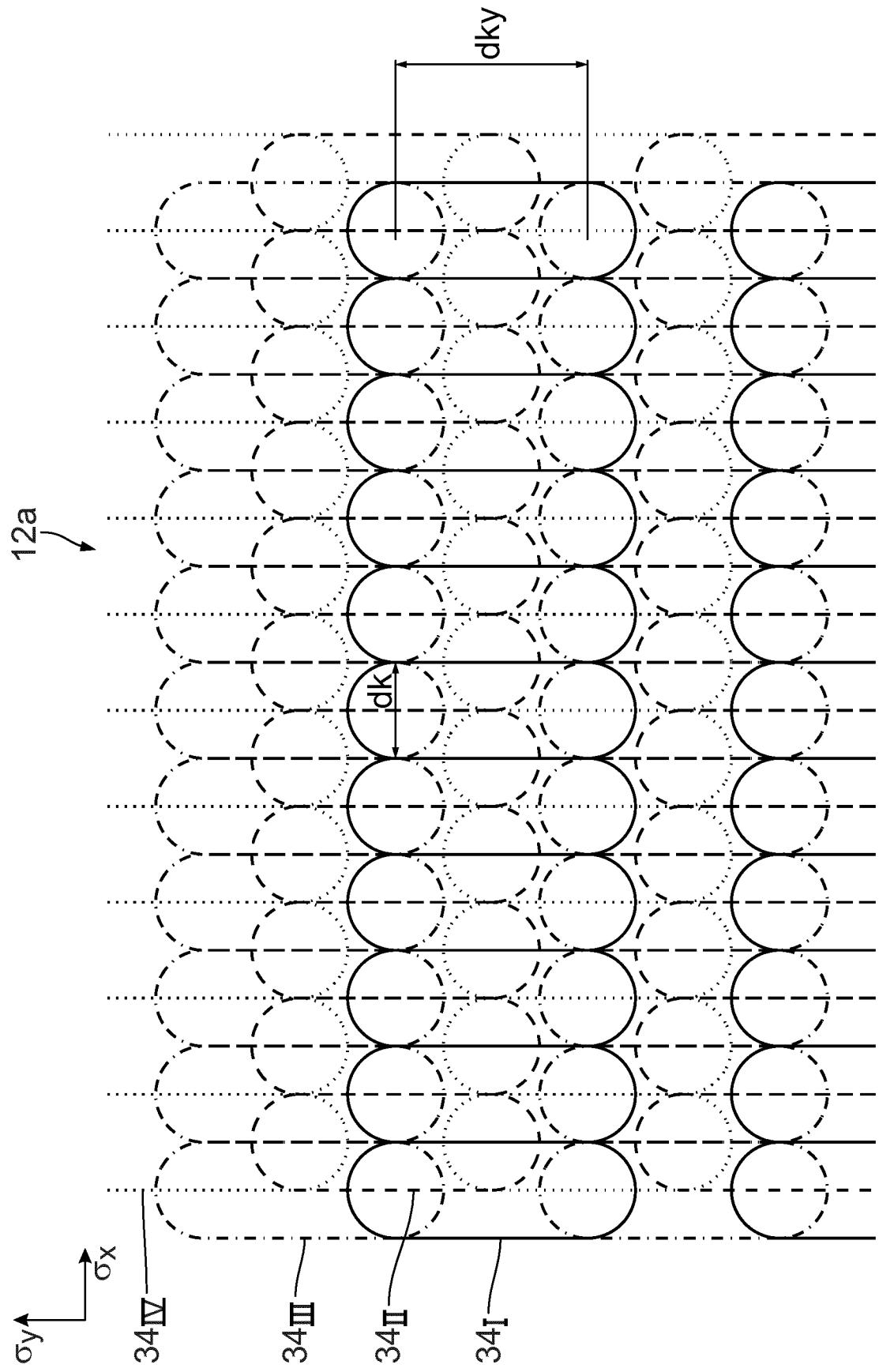
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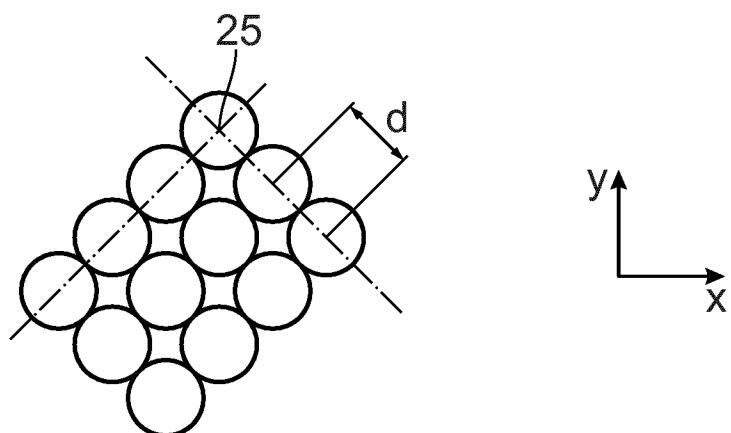
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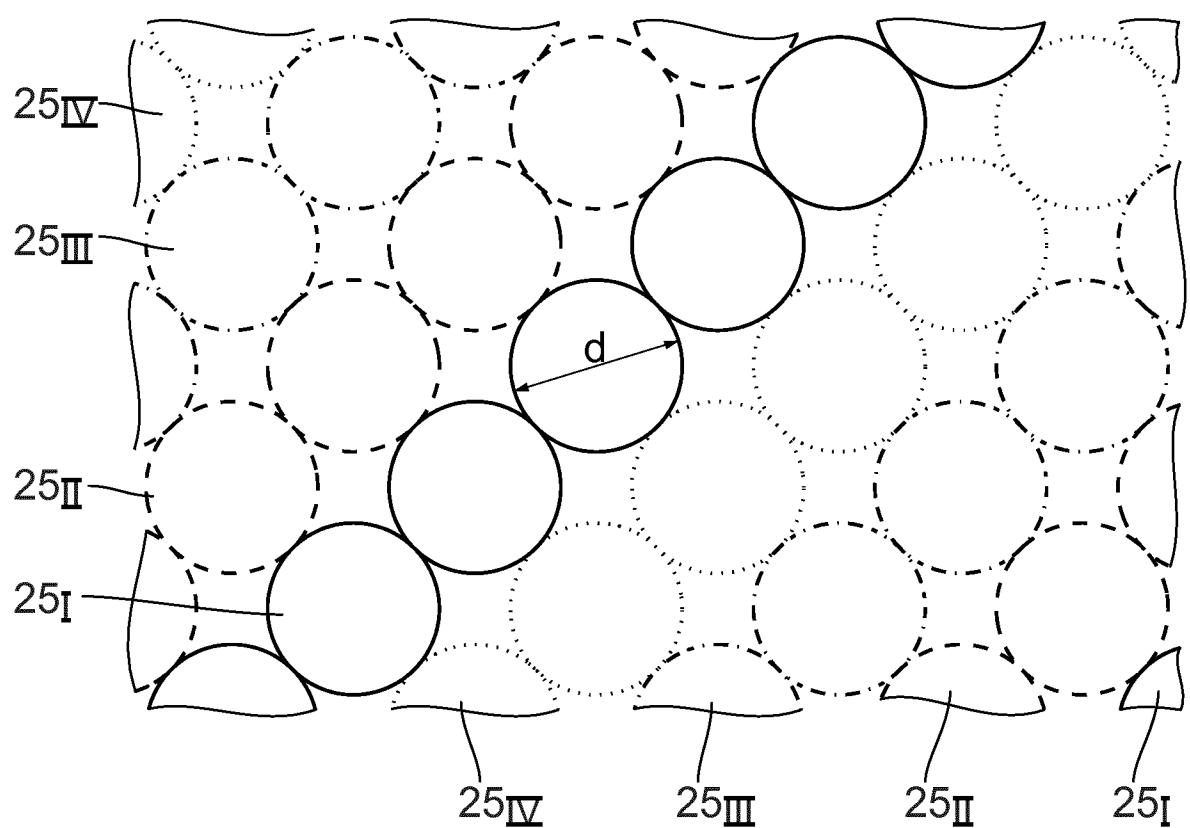
Fig. 15
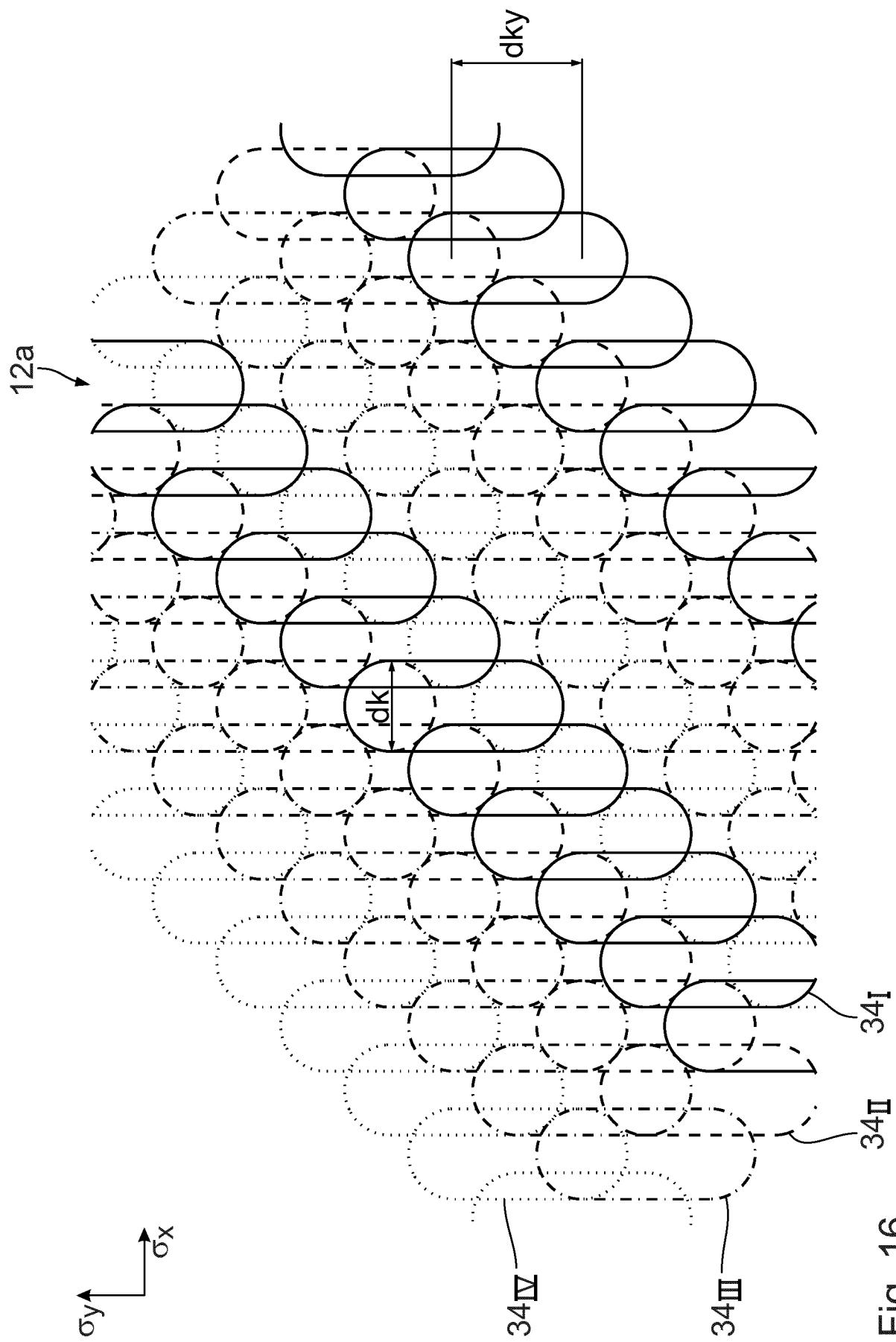
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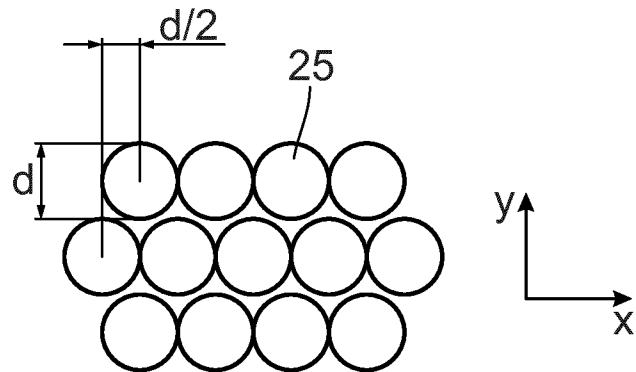
Fig. 17
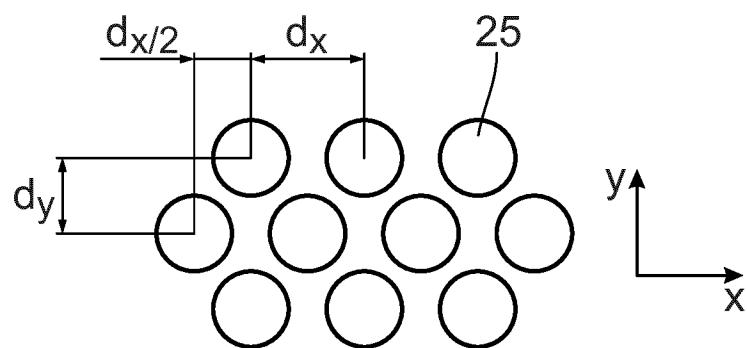
Fig. 18
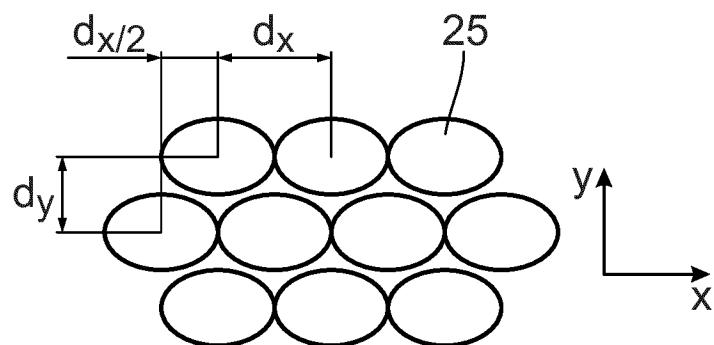
Fig. 19

INTERNATIONAL SEARCH REPORT

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G03F

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

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	paragraphs [0051] - [0060]; figure 3 -----	2-8
A	DE 10 2012 210961 A1 (ZEISS CARL SMT GMBH [DE]) 6 June 2013 (2013-06-06) paragraph [0030]; figures 1, 3 -----	2-8
A	US 2011/122392 A1 (FIOLKA DAMIAN [DE] ET AL) 26 May 2011 (2011-05-26) paragraphs [0117] - [0140]; figures 12, 14 -----	1

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 December 2015	07/01/2016

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

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

1

INTERNATIONAL SEARCH REPORT

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