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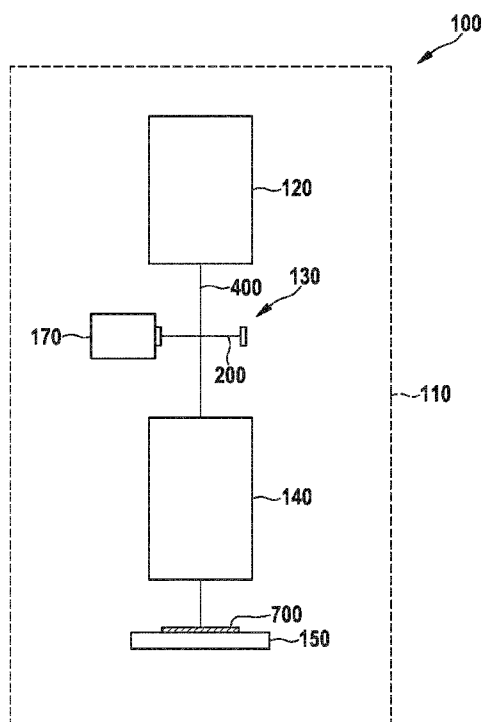
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(54) Title: PROJECTION EXPOSURE SYSTEM FOR EUV LITHOGRAPHY AND METHOD FOR OPERATING THE PROJEC-
TION EXPOSURE SYSTEM



(57) Abstract: The invention relates to a projection exposure system (100) for EUV lithography comprising: - an illumination device (120) for generating EUV radiation (400) having defined properties, - a reticle stage (130) arranged in the beam path of the illumination device (120) and serving for receiving a transmission reticle (200), and - a projection optical unit (140) disposed optically downstream of the reticle stage (130) and serving for projecting the EUV radiation (400) transmitted through the transmission reticle (200) onto a wafer stage (150).

Fig. 5



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Description

Projection exposure system for EUV lithography and method for operating the projection exposure system

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The invention relates to a projection exposure system for EUV lithography. The invention furthermore relates to a transmissive reticle and a reticle arrangement for such a projection exposure system.

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This patent application claims the priority of the German patent application DE 10 2012 219 545.9, the disclosure content of which is hereby incorporated by reference.

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For producing semiconductor components, photolithographic methods are used, inter alia, wherein the structure pattern to be produced is projected on a reducing scale with the aid of a mask (reticle) onto a functional layer coated with a light-sensitive layer and is transferred to the functional

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layer after the development of the photosensitive layer by means of an etching method. The production of ever finer structures makes it necessary to use light having ever shorter wavelengths for the lithography process. Current lithography methods therefore employ electromagnetic radiation into the range of extreme ultraviolet light (EUV). Since the EUV radiation is absorbed to a great extent by most known materials, reflective components are generally used in EUV lithography for the projection exposure systems. For this purpose, specially designed mirror systems are required which direct

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the radiation onto the reticle in a suitable manner and subsequently project it onto a desired region of a semiconductor wafer. In this case, the known EUV lithography systems employ reflective reticles designed either in the form of a reflective carrier layer with a structured absorber layer arranged thereon, or in the form of an absorbent carrier layer with a structured reflection layer arranged thereon. In the case of the reflective reticles having a reflective carrier layer and

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a structured absorber layer, on account of the required spatial separation of the incident and reflected beam cones with increasing numerical aperture (NA) and thus smaller structures to be imaged, undesired shading effects of the radiation arise as a result of the absorption or absorber structures arranged on the carrier layer, which have to have a minimum thickness for sufficient absorption. This Manhattan effect, as it is called, significantly reduces the proportion of EUV radiation arriving at the wafer. Furthermore, the imaging quality can be further impaired by further optical effects associated with the shading.

However, the use of a reflective reticle also entails further problems. In this regard, any displacement of the reflective reticle within the optical arrangement of the exposure projection system leads to faulty imagings on the exposed wafer. Therefore, movements of the reflective reticle along its surface normal have to be continuously compensated for by complex tracking of the imaging optical unit and/or of the wafer.

Therefore, it is an object of the invention to improve EUV lithography. This object is achieved by means of a projection exposure system according to Claim 1. Furthermore, the object is achieved by means of a transmissive reticle according to Claim 12 and by means of a reticle arrangement according to Claim 16. Further advantageous embodiments are specified in the dependent claims.

In this case, a projection exposure system for EUV lithography is provided, comprising an illumination device for generating EUV radiation having defined properties, a reticle stage arranged in the beam path of the illumination device and serving for holding a transmission reticle, and a projection optical unit disposed optically downstream of the reticle stage and serving for projecting the EUV radiation transmitted through the transmission reticle onto a wafer stage.

With the use of a transmissive reticle it is possible to achieve a substantially perpendicular transmission of the EUV radiation through the reticle, as a result of which in turn the shading effects that are caused by the absorber structures arranged on the reticle carrier layer can be reduced as far as possible. Consequently, the imaging aberrations associated therewith can be avoided, and the imaging quality can be improved.

One embodiment provides for the projection exposure system furthermore to comprise a scanning device arranged in the region of the reticle stage and serving for scanning the reticle, wherein the scanning device comprises a first scanning mirror for directing the EUV radiation generated by the illumination device onto the transmission reticle arranged in the reticle stage.

In a further embodiment, the scanning device is designed to scan the transmission reticle arranged in the reticle stage in a scanning manner by means of a combined translation and tilting movement of the first scanning mirror. Consequently, the scanning device allows the scanning of the transmission reticle with the EUV beam, without the movement of the transmission reticle.

In a further embodiment, the scanning device furthermore comprises a second scanning mirror for coupling the EUV radiation transmitted through the transmission reticle into the projection optical unit. In this case, the scanning device is designed to scan the transmission reticle arranged in the reticle stage in a scanning manner by means of a combined translation and tilting movement of the scanning mirrors. The scanning device allows the scanning of the transmission reticle with the EUV beam, without the movement of the transmission reticle. As a result of the static arrangement of the transmission reticle that is possible in this way, dynamic effects, such as oscillations, for example, parallel to the

normal to the surface of the reticle (out-of-plane oscillations), which can typically occur upon corresponding mechanical excitation of the reticle, are reduced as far as possible. This in turn makes it possible to improve the imaging
5 quality of the exposure projection system since the reduced out-of-plane movement of the reticle leads to smaller imaging aberrations particularly in the case of non-telecentric lenses. Furthermore, reticles having a smaller thickness can be used, which in turn leads to an increase in the light in-
10 tensity available at the wafer.

A further embodiment provides for the scanning device to furthermore comprise a first deflection mirror, which is arranged between the first scanning mirror and the reticle
15 stage and which is designed to direct the EUV radiation reflected from the first scanning mirror with a combined translation and tilting movement at a substantially perpendicular angle onto the transmission reticle arranged in the reticle stage. Furthermore, a further embodiment provides for the
20 scanning device to furthermore comprise a second deflection mirror, which is arranged between the reticle stage and the second scanning mirror and which is designed to direct the EUV radiation that is being transmitted through the transmission reticle arranged in the reticle stage at a substantially
25 perpendicular angle with combined translation and tilting movements onto the second scanning mirror. With the aid of these deflection mirrors it is possible to achieve substantially perpendicular passage of radiation through the transmission reticle in any scanning position. This in turn re-
30 duces shading effects and thus improves the imaging quality of the projection exposure system.

A further embodiment provides for the combined translation and tilting movements of the mirrors of the scanning device
35 to be coordinated with one another in such a way that substantially the same optical path length (OPL) for the EUV radiation from the reticle stage to the projection optical unit

results for each scanning position of the mirrors. This prevents a variation of the optical path length which is equivalent to a movement of the transmission reticle along the optical axis. Thus, imaging aberrations can be reduced and the
5 imaging quality can be improved.

A further embodiment provides for the projection lens to be designed to be telecentric at least on the input side. This improves the imaging quality of the projection exposure system since the input-side telecentricity of the projection
10 lens causes a reduced sensitivity toward changes in the position of the transmission reticle along the optical axis.

A further embodiment provides for the projection exposure
15 system to comprise a vacuum chamber having a first partial chamber, which receives the illumination device, and a second partial chamber, which receives the projection lens, and at least one partition introducible between the illumination device and the reticle stage and/or between the projection lens
20 and the reticle stage and serving for separating the two partial chambers. With the aid of said partition, the two partial chambers can be ventilated and evacuated independently of one another, which makes it possible, for example, to leave the reticle in the ultrahigh vacuum whilst at the same
25 time ventilating one of the two partial chambers. Furthermore, with the aid of such a partition, the removal of the reticle can also be simplified since only part of the vacuum chamber 110 has to be ventilated for this purpose. The removal of the reticle can furthermore be simplified by a second
30 partition arranged on the opposite side of the reticle stage relative to the first partition. With the aid of the two partitions, the central section of the vacuum chamber that receives the reticle stage can be partitioned from the two partial chambers, such that it is necessary only to ventilate and/or evacuate the central vacuum chamber section.
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A further embodiment provides for the projection exposure system furthermore to comprise a damping device for damping oscillatory movements of the transmission reticle arranged in the reticle stage. In this case, the damping device is designed to reduce the oscillatory movements of the transmission reticle by blowing a suitable gas on the transmission reticle and/or by means of active acoustic or mechanical damping. Out-of-plane movements of the transmission reticle and imaging aberrations associated therewith can be reduced with the aid of such a damping device. Furthermore, such a damping device can prevent the transmission reticle from touching further components of the projection exposure system. In this regard, particularly in the case of transmission reticles which are protected by a pellicle, by feeding the suitable gas into the interspace formed by the transmission reticle and the pellicle, it is possible to generate an excess pressure in said interspace and this forces the two components apart. Furthermore, the excess pressure reduces the risk of contamination for the sensitive mask structures.

A further embodiment provides for the projection lens to comprise an input mirror, the angle-of-incidence spectrum or angle-of-incidence distribution of which is designed to be mirror-symmetrical and/or rotationally symmetrical. On account of the symmetrical angle-of-incidence spectrum, narrowerband reflection layers can be used for the input mirror of the projection lens. This reduces undesired optical effects associated with broadband reflection layers.

Furthermore, a transmission reticle for an EUV lithography projection exposure system is provided, comprising a carrier layer composed of a silicon, germanium, molybdenum, niobium and/or zirconium material and a structured absorber layer arranged on the carrier layer. A carrier layer formed from the materials mentioned can be produced with a particularly small layer thickness (e.g. 25 nm silicon layer) which has a sufficient transparency to the EUV light used. At the same time,

carrier films composed of the materials mentioned have a sufficient stability to withstand the mechanical loads during the handling and use of the transmission reticle.

5 One embodiment provides for the carrier layer to comprise a layer stack composed of silicon and/or germanium layers separated from one another in each case by a layer of zirconium silicide. Such a carrier layer has a particularly high transparency to EUV light. On the other hand, an adaptation of the
10 crystal structures of the two layers and, associated therewith, the mechanical stability of the carrier layer are improved with the aid of such a transition layer.

A further embodiment provides for the absorber layer to be
15 formed from a material containing nickel and/or tantalum nitride. These materials have relatively good absorption qualities for the EUV light used. Furthermore, the materials mentioned, on account of their relatively high melting points, can withstand, without being damaged, the high temperatures
20 (e.g. $T > 500^{\circ}\text{C}$) occurring in the absorber layer in EUV projection exposure systems.

A further embodiment provides for the carrier layer to be provided at least on one side with a protective layer containing ruthenium, rhodium, carbon, iridium and/or silicon
25 nitride. With the aid of such a protective layer, it is possible to protect the sensitive carrier layer against various influences, such as e.g. oxidation. It is thus possible to ensure the high transmission of the carrier layer for the EUV
30 light over a long time. Furthermore, these materials with the small layer thicknesses used do not cause any relevant attenuation of the EUV radiation.

Furthermore, a reticle arrangement is provided, comprising a
35 transmission reticle and at least one pellicle composed of a silicon-, germanium- and/or zirconium-containing material arranged in front of the transmission reticle. Such a pellicle

prevents the contamination of the reticle. Since, at the short wavelengths used in EUV lithography, even extremely small contaminations of the reticle can lead to imaging aberrations, a uniform imaging quality of the transmission reticle can be ensured with the aid of the pellicle. Since cleaning is scarcely feasible on account of the relatively small thickness (e.g. 50 - 150 nm) of the transmission reticle, the lifetime of an EUV transmission reticle can be significantly prolonged with the aid of the pellicle.

One embodiment provides for the transmission reticle and the pellicle to be enclosed by a common frame structure comprising at least one feed opening for feeding a gas into the interspace between transmission reticle and pellicle. Such an arrangement allows the reticle and the pellicle to be mechanically stabilized with the aid of an excess pressure generated in the interspace by the gas feed. Furthermore, cooling of the reticle or the absorber layer can be achieved with the aid of the gas.

The invention is described in greater detail below with reference to figures, in which:

Figure 1 shows by way of example a reflective reticle for EUV lithography for elucidating the Manhattan effect caused by oblique light incidence;

Figure 2 shows a further reflective reticle having smaller structures for elucidating the relationship between structure size and Manhattan effect;

Figure 3 shows a transmission reticle for EUV lithography comprising a transparent carrier layer and absorber structures arranged thereon;

Figure 4 shows a further transmissive reticle, comprising a carrier layer constructed in the form of a layer stack;

Figure 5 schematically shows a projection exposure system for EUV lithography designed for the use of a transmission reticle;

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Figure 6 schematically shows the cross section through a reticle arrangement comprising a reticle, a pellicle and a frame encompassing the two structures, with a feed opening for a suitable gas;

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Figure 7 schematically shows the construction of a projection exposure system comprising an optical scanning device for scanning the transmission reticle in a scanning manner;

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Figure 8 shows a detail illustration of the scanning device from figure 7 for elucidating the geometrical relationship;

Figure 9 shows an exemplary embodiment of an EUV transmission reticle comprising specially adapted absorption structures;

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Figure 10 shows a modification of the projection exposure system from figure 7 with additional deflection mirrors for ensuring the substantially perpendicular beam path in the region of the reticle stage;

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Figure 11 shows by way of example an excerpt from a projection lens comprising two mirrors; and

Figure 12 shows a schematic illustration of an exemplary projection exposure system comprising two partial chambers that can be separated from one another by means of introducible partition apparatuses.

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In EUV lithography by means of reflective reticles, oblique light incidence on the reticle surface occurs on account of the required separation between incident beam direction and reflective beam direction. **Figure 1** shows by way of example

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the reflection of EUV radiation 400 at a reflective reticle 300. In this case, the reticle 300 comprises a carrier layer 310, which is reflective in the EUV range, and a structured absorber layer 320 arranged on said carrier layer 310. On account of the minimum layer thickness 321 of the absorber layer 320 required for the sufficient absorption of the EUV radiation 400, shielding effects as a result of the absorber structures occur in the event of oblique light incidence. This Manhattan effect, as it is called, reduces the proportion of the effectively reflective surface of the carrier layer 310 and, associated therewith, the proportion of the useably reflected EUV radiation 400. In this case, the shading effect increases as the thickness 321 of the absorber layer 320 increases.

As shown in **figure 2**, however, the shading effect is also dependent on the distances between the structures formed in the absorber layer 320. In this regard, the reflected and thus usable proportion of the EUV radiation 400 decreases significantly with decreasing structure widths.

In order to reduce the shading effects, the projection exposure system proposed here uses a transmissive reticle or transmission reticle 200 comprising a carrier layer 210, which is transparent to EUV light, and a structured absorber layer 220 arranged on the carrier layer 210. As is shown in **figure 3**, the almost perpendicular passage of radiation through the transmission reticle 200 allows a shading-free or almost shading-free imaging of the structures produced in the absorber layer 320. Preferably silicon, germanium, zirconium, molybdenum, niobium or a combination of these elements, such as e.g. Zr/ZrSi₂ or Mo/NbSi₂, is used as material for the carrier layer 310. In order to ensure sufficient transmission of the EUV radiation 400 through the reticle 200, a carrier layer 210 having the smallest possible layer thickness 212 is used. In this regard, by way of example, the carrier layer 210 used can be an approximately 50 nm or approximately

100 nm thick silicon layer having a transmission loss of 8% or approximately 16%. Absorber material used can be, for example, tantalum nitride (TaN) having a layer thickness of approximately 45 nm, which enables sufficient EUV absorption.

5 In principle, any suitable material can be used as absorber, provided that with the desired layer thickness it enables a sufficiently high absorption of the EUV radiation 400 and is suitable for ultrahigh vacuum (UHV), readily structurable and thermally stable. Since the absorber regions of the reticle
10 become significantly hotter than the transmissive regions on account of the higher absorption of the EUV radiation 400 and at the same time on account of heat dissipation being reduced by the ultrahigh vacuum, in particular thermally resistant materials such as e.g. nickel (melting point above 1400°C) or
15 other metals are appropriate as absorber.

In order to protect the sensitive surface of the transmissive or transparent regions of the reticle 200, the carrier layer 210 can be equipped on one or both sides by means of a thin
20 protective layer (cap layer) 230. By way of example, ruthenium, rhodium, carbon, iridium or silicon nitride (Si_3N_4) is suitable as material for said protective layer 230.

In order to ensure a sufficient transmissivity or transparency to the EUV radiation 400 used, and at the same time the highest possible stability of the film-like reticle, the carrier layer 210 can also be constructed in a multilayered fashion. In this case, **figure 4** shows a transmission reticle 200 having a carrier layer 210 constructed in the form of a
30 layer stack 211 composed of different materials. In this case, the layer stack 211 can be constructed from thin silicon and germanium layers that can respectively be separated from one another by a zirconium silicide (ZrSi_2) layer.

35 **Figure 5** schematically shows the construction of an EUV projection exposure system 100 using a transmissive reticle 200. In this case, the projection exposure system 100 comprises an

illumination device 120 for generating defined EUV radiation 400, a reticle stage 130 disposed optically downstream of the illumination device 120 and serving for receiving a transmission reticle 200, and a projection lens 140, which is disposed optically downstream of the reticle stage 130 and images the EUV radiation 400 transmitted through the transmission reticle 200 arranged in the reticle stage 130 onto a wafer 700 arranged in a wafer stage 150 in a reducing manner. As is shown in figure 5, radiation passes through the transmission reticle 200 substantially perpendicularly in this arrangement.

It is advantageous for the transmission reticles 200 used in connection with the transmissive projection exposure system 100 to be made as thin as possible and with the largest possible diameter in order to ensure sufficient transmission and at the same time to be able to image as many structures as possible in an exposure process; however, the transmission reticles 200 can react relatively sensitively to any acceleration on account of their film-like construction. In particular, oscillations of the reticle 200 in the form of microscopic location- and time-dependent displacements of the object plane 202 can be excited in each case. For the purpose of damping said oscillations, the projection exposure system 100 can be equipped with a damping device 170, which actively counteracts the movements of the reticle 200. By way of example, such oscillations can be reduced by blowing on the transmission reticle 200 uniformly or in a pulsed manner. Furthermore, oscillatory movements of the transmission reticle 200 can be reduced or compensated for by means of actuators arranged outside the optically used reticle region, with the use of the superposition principle. The actuation can be effected mechanically or acoustically, for example.

The damping device 170, illustrated in the form of a function block in figure 5, can in this case be designed either as

part of the reticle stage 130 or in the form of a separate device.

For the purpose of better handling, the film-like transmission reticle 200 is clamped in a frame structure 520. In order to protect the sensitive reticle film 200, it is possible to use a pellicle 510 arranged in front of the reticle 200 preferably on that side of the reticle which bears the absorber structures. **Figure 6** shows a reticle arrangement 500 comprising the frame structure 520, the film-like transmission reticle 200 enclosed in the frame structure, and the pellicle 510 arranged at a small distance from the reticle 200 and likewise enclosed in the frame structure 520. Said distance is preferably between 1 nm and 10 nm. In this case, the reticle 200 and the pellicle 510 are arranged with respect to one another in such a way that the absorber structures 220 situated on the carrier layer 210 of the reticle 200 are situated in the interspace 530 protected by the two films 200, 510.

Since both the reticle 200 and the pellicle 510 are designed in the form of thin films (reticle thickness for example 70 to 120 nm, pellicle thickness for example 20 nm), they typically react very sensitively to vibrations of the reticle arrangement 500. As a result of the oscillations induced in this case in the two films 200, 510, there is in this case the risk, in principle, of the two films 200, 510 touching one another. In order to prevent this, in the case of the reticle arrangement 500, a suitable gas can be fed into the interspace 530 between the two films 510, 200. As a result of the slight excess pressure generated in this case, the films 200, 510 are pressed convexly outward and the risk of a collision is thus reduced. A suitable gas is hydrogen (H_2), for example, which is fed for example through a suitable feed opening 521 in the frame structure 520. In this case, the excess pressure also effectively prevents the soiling or contamination of the interspace 530 by undesired substances.

In the case where no pellicle 510 is used, the reticle film 200 can be stabilized by a gas flow being used to blow directly on the reticle 200. By way of example, hydrogen (H₂) at a low pressure of a few pascals (e.g. approximately 5 Pa or approximately 10 Pa) is suitable for this purpose. As a result of the gas flow 600, the movement of the thin reticle film 200 along the optical axis can be reduced and a higher imaging quality can thus be achieved.

In both cases, cooling of the film-like transmission reticle 200 can also be achieved with the aid of the gas flow 600.

However, the reticle film 200 can also be stabilized by an active damping which acts on the reticle film 200 mechanically or acoustically.

Besides an active oscillation damping, the problem that arises during the imaging of the mask structures on the wafer with the reticle displacement along the optical axis can be combated by using a projection lens 140 constructed in a telecentric fashion on the input side. As a result of the telecentricity of the projection lens 140, displacements of the reticle 200 along the optical axis affect the imaging quality on the wafer plane only to a negligible extent compared with a reflective reticle. In this regard, by way of example, it is also possible to compensate for positional errors of the reticle 200 in the reticle stage 130.

In order to avoid oscillations of the film-like transmission reticle 200 and the optical and mechanical problems associated therewith, it can be expedient to arrange the reticle 200 in a stationary or immobile manner in the reticle stage 130 and to scan it in a scanning manner by the use of a specific scanning device. Such a scanning device 160 for scanning the reticle 200 can be realized for example with the aid of one or a plurality of movable mirrors which guide the EUV

radiation 400 over the transmission reticle 200 in a scanning manner. In this respect, **figure 7** shows by way of example the basic construction of such a scanning device 160. In this case, the scanning device 160 comprises two scanning mirrors 161, 162, which are movable synchronously with one another and which perform a scanning of the stationary transmission reticle 200 in each case by means of a combined translation and tilting movement. The first scanning mirror 161, which is arranged between the illumination device 120 and the reticle 200 and is movable along a free path curve, directs the EUV radiation 400 generated by the illumination device 120 onto a specific location of the transmission reticle 200. By contrast, the second scanning mirror 162, which is arranged between the reticle stage 130 and the projection lens 140 and is likewise movable along a free path curve, directs the EUV radiation 400 transmitted through the reticle 200 onto the entrance pupil of the projection lens 140.

In order to elucidate the scanning process, figure 7 illustrates the position of the scanning mirrors 161, 162 by way of example for two different points in time, the reference signs 161 and 162 designating the scanning mirrors or position of the scanning mirrors at a first point in time and the reference signs 161' and 162' designating the scanning mirrors or position of the scanning mirrors at a second point in time. In this case, at the first point in time the first scanning mirror is situated at the level of the lower edge of the reticle 200 and directs the EUV radiation 400 emitted by the illumination device 120 in the direction of the second scanning mirror 162, which is situated at approximately $\frac{2}{3}$ of the height of the reticle 200 at this point in time. Radiation passes through the reticle 200 approximately over $\frac{1}{3}$ of its height in this position.

After a translation of the first scanning mirror in the direction of the illumination device 120 and a slight tilting in the clockwise direction, the EUV radiation 400 from the

illumination device 120 is now directed by the first scanning mirror 161' into an upper section in the region of the reticle 200, radiation passing through the reticle 200 almost perpendicularly in this scanning position. The second scanning mirror 162', which has likewise moved upward and been tilted in the clockwise direction at this point in time, directs the EUV radiation 400' transmitted almost perpendicularly through the reticle 200 once again in the direction of the projection optical unit 140. In this case, the scanning mirrors 161, 162 are moved on free path curves which lie on the optical axes of the illumination device 120 and of the projection lens 140, respectively, in the present case. In order to ensure a high imaging quality, it is necessary that the optical path length covered by the EUV radiation 400 after transmission through the reticle as far as the entrance pupil of the projection lens 140 does not vary with the scanning position or location of the scanning mirrors 161, 162. In this case, the position of the scanning mirrors 161, 162 must be in a specific relationship with the angle α at which the EUV radiation 400 is transmitted through the reticle 200. The exact geometrical relationships are evident from **figure 8**, which illustrates a detail illustration of the optical arrangement from figure 7. In this case, α corresponds to the transmission angle through the reticle 200, $h(\alpha)$ corresponds to the reticle passage height, d corresponds to the distance between the second scanning mirror 162 and the reticle 200, l_1 corresponds to the optical sublength from the reticle 200 as far as the second scanning mirror 161, l_2 corresponds to the optical sublength from the second scanning mirror 162 as far as a point A determined by the reticle passage height $h(\alpha)$, and OPL corresponds to the optical path length of the EUV light radiation 400 from the reticle 200 as far as the point B situated at the level of the lower edge of the reticle 200.

Figure 8 reveals that the optical path length OPL is composed of the sum of the lengths l_1 , l_2 and the passage height $h(\alpha)$ corresponding to the distance between the points A and B.

5 The following thus results for the optical path length OPL:

$$(*) \quad OPL = \frac{d}{\cos \alpha} + \frac{d \cdot \sin \alpha}{\cos \alpha} + h(\alpha)$$

or

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$$\frac{OPL - h(\alpha)}{d} = \frac{1 + \sin \alpha}{\cos \alpha}$$

As can be seen from this rearrangement, the set of values of

$$15 \quad f(x) = \frac{1 + \sin x}{\cos x} \quad (x \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]) \quad \text{comprises all positive real numbers } \mathbb{R}^+$$

and thus the equation (*) is solvable for $h(\alpha) < OPL$. A solution to the equation

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$$OPL = \frac{d}{\cos \alpha} + \frac{d \cdot \sin \alpha}{\cos \alpha} + h(\alpha)$$

can be determined for example by means of quadratic supplementation by virtue of the substitution $k = \sin \alpha$, $\cos \alpha = \sqrt{1 - n^2}$.

25 In the case of the scanning device 160 shown here by way of example, the passage angle α of the EUV radiation 400 through the reticle 200 varies depending on the position of the scanning mirrors 161, 162. In order to combat losses of imaging quality that possibly result from this, this change in angle
30 can already be taken into account during the production of the absorber structures on the reticle 200. This can be done, on the one hand, by adapting the width and position of the absorber structures to be imaged on the carrier layer 210. As an alternative to this, the absorber structures can be pro-

duced using a special production method with flank angles dependent on the respective position on the reticle 200. Such a transmission reticle 200 is shown for example in **figure 9**.

5 As an alternative to this, substantially perpendicular passage of the EUV radiation 400 through the reticle can be ensured by using additional optical elements, such as e.g. additional deflection mirrors. In this respect, **figure 10** shows by way of example a projection exposure system 100 comprising
10 a modified scanning device 160. The scanning device 160 has additional deflection mirrors 163, 164 respectively situated between the reticle 200 and a scanning mirror 161, 162. In this case, the first deflection mirror 163 serves for directing the EUV radiation 400 reflected from the first scanning
15 mirror 161 onto the reticle 200 at a perpendicular or substantially perpendicular angle. Analogously thereto, the second deflection mirror 164 directs the EUV radiation 400 passing perpendicularly through the reticle 200 onto the second scanning mirror 162. In this case, the two deflection mirrors
20 163, 164 are adjusted depending on the scanning position in respectively combined translation and tilting movements along free path curves. This expediently takes place synchronously with the translation and tilting movements of the scanning mirrors 161, 162. In order to comply with the condition of
25 the constant optical path length for the EUV radiation 400 from the reticle 200 as far as the projection lens 140, the detour via the second deflection mirror 164 has to be concomitantly taken into account when calculating the optical path length OPL.

30 As an alternative to the use of additional deflection mirrors, substantially perpendicular transmission of the EUV radiation 400 through the reticle 200 can, if appropriate, also be achieved by means of a tilting movement of the reticle 200
35 that takes place synchronously with the translation of the two scanning mirrors 161, 162.

In contrast to a projection exposure system designed for a reflective reticle, the projection exposure system which is proposed here and which is designed specifically for a transmission reticle can have a projection lens designed to be telecentric on the input side. This affords many advantages since the imaging quality of such a projection lens is relatively insensitive to displacements of the reticle along the optical axis. A further advantage of the EUV projection exposure system 100 presented here is that the use of a transmissive reticle 200 makes it possible to achieve a mirror-symmetrical or even rotationally symmetrical distribution of the angle of incidence in the path from the reticle 200 to the - in the light direction - first mirror 141 (input mirror) of the projection lens 140. In this respect, **figure 11** shows by way of example an EUV projection exposure system 100 comprising a transmission reticle 200, through which radiation passes substantially perpendicularly, and a projection lens 140 disposed optically downstream of the reticle 200 and having a first mirror 141, serving as input mirror, and a second mirror 142, wherein the mirrors are illustrated here only by way of example. The EUV radiation 400 focused in the region of the reticle 200 enters into the projection device 140 in the form of a beam cone 410, wherein only the chief ray 411 and the two marginal rays 412, 413 are illustrated here. On account of the symmetrical beam guiding from the reticle 200 to the projection lens 140, a symmetrical angle-of-incidence distribution arises for arbitrary planes 420, 430 parallel to the reticle plane 202 along the chief ray 411 of the EUV radiation 400 and for the input mirror 141. In this case, symmetrical means mirror-symmetrical or even rotationally symmetrical. On account of the overall smaller angle-of-incidence spectrum, it is possible to use narrower band reflection layers for the first mirror 141 in comparison with a projection exposure system without a corresponding mirror-symmetrical or rotationally symmetrical angular spectrum.

The angle-of-incidence spectrum on the first mirror 141 is dependent, in principle, on the numerical aperture (NA) of the imaging system. In the case of reflective systems, the angular spectrum for the same numerical aperture, on account
5 of the oblique incidence of light at the reticle, is greater than in the case of almost perpendicular transmission through a transmissive reticle.

As a result of the narrower band configuration of the reflective layers of the first mirror 141, it is possible to reduce
10 undesired effects such as low transmission, absorption and loss of contrast.

The transmissive projection exposure system 100 furthermore
15 allows the illumination system 120 to be separated from the projection lens 140 by means of partitions introducible in the region of the reticle stage. In this respect, **figure 12** shows by way of example a transmissive projection exposure system 100 for EUV lithography comprising a vacuum chamber
20 110 formed from two partial chambers 111, 112. The first partial chamber 111 contains the illumination system 120, while the second partial chamber 112 accommodates the projection lens 140 and also, if appropriate, the wafer stage 150. The two partial chambers 111, 112 can be partitioned from one another by means of two introducible partitions 113, 114 arranged on both sides of the wafer stage 130. This firstly enables partial ventilation of the system, i.e. of the first or
25 of the second partial chamber 111, 112. This is expedient, in particular, if the illumination system is ventilated on account of maintenance work. Possible contamination of the projection system is prevented in this case. Furthermore, the partitions 113, 114 allow the transmission reticle 200 to be removed or changed, without the need to ventilate the two
30 partial chambers 111, 112. As is furthermore illustrated in figure 12, both partial chambers 111, 112 have separate vacuum pumps 116, 117.

Although the invention has been more specifically illustrated and described in detail by means of the preferred exemplary embodiments, the invention is not restricted by the examples disclosed. Rather, a person skilled in the art can also derive other variations therefrom for example through combination of the features of different embodiments, without departing from the scope of protection of the invention.

As an example, a scanning device may be realized with only one scanning mirror in contrast to the embodiment described above which has two scanning mirrors.

List of reference signs

	100	projection exposure system
	110	vacuum chamber
5	111	first partial chamber
	112	second partial chamber
	113	central chamber region
	114	first partition
	115	second partition
10	116	first vacuum pump
	117	second vacuum pump
	120	illumination device
	130	reticle stage
	140	projection lens
15	141	first mirror of the projection lens
	142	second mirror of the projection lens
	143	entrance pupil
	150	wafer stage
	160	scanning device
20	161	first scanning mirror
	162	second scanning mirror
	163	first deflection mirror
	164	second deflection mirror
	165	rotation axis of the first scanning mirror
25	166	rotation axis of the second scanning mirror
	170	damping device
	200	transmissive reticle
	202	reticle plane
30	210	transmissive carrier layer
	211	layer stack
	212	layer thickness of the carrier layer
	220	structured absorber layer
	230	protective layer
35	300	reflective reticle
	310	reflective carrier layer

	320	structured absorber layer
	321	thickness of the absorber layer
	322	distance between the absorber structures
5	400	EUV radiation
	410	beam cone
	411	chief ray
	412, 413	marginal rays
	420	first reference plane
10	430	second reference plane
	440	third optical plane
	500	reticle arrangement
	510	pellicle
15	520	holding frame
	521	opening in the holding frame
	530	volume enclosed by the reticle and pellicle
	600	gas
20	700	wafer
	d	distance between transmission reticle and scanning mirror
25	h	height of the EUV beam at the transmission reticle
	α	angle of the EUV beam upon passing through the transmission reticle
	OPL	optical path length
	l_1	first sublength
30	l_2	second sublength

Claims

1. Projection exposure system (100) for EUV lithography comprising:

- 5 - an illumination device (120) for generating EUV radiation (400) having defined properties,
 - a reticle stage (130) arranged in the beam path of the illumination device (120) and serving for receiving a transmission reticle (200),
10 - a scanning device (160) arranged in the region of the reticle stage (130) and serving for scanning the reticle, wherein the scanning device (160) comprises a first scanning mirror (161) for directing the EUV radiation (400) generated by the illumination device (120) onto
15 the transmission reticle (200) arranged in the reticle stage (130), and
 - a projection optical unit (140) disposed optically downstream of the reticle stage (130) and serving for projecting the EUV radiation (400) transmitted through
20 the transmission reticle (200) onto a wafer stage (150).

2. Projection exposure system (100) according to Claim 1, wherein the scanning device (160) is designed to scan the transmission reticle (200) arranged in the reticle stage (130) in a scanning manner by means of a combined
25 translation and tilting movement of the first scanning mirror (161).

3. Projection exposure system (100) according to either of
30 Claims 1 and 2,
 wherein the scanning device (160) furthermore comprises a second scanning mirror (162) for coupling the EUV radiation (400) transmitted through the transmission reticle (200) into the projection optical unit (140).

35 4. Projection exposure system (100) according to Claim 3, wherein the scanning device (160) is designed to scan

the transmission reticle arranged in the reticle stage (130) in a scanning manner by means of combined translation and tilting movements of the scanning mirrors (161, 162).

5

5. Projection exposure system (100) according to Claim 4 or 5,

10

wherein the scanning device (160) furthermore comprises a first deflection mirror (163), which is arranged between the first scanning mirror (162) and the reticle stage (130) and which is designed to direct the EUV radiation (400) reflected from the first scanning mirror (161) with a combined translation and tilting movement at a substantially perpendicular angle onto the transmission reticle (200) arranged in the reticle stage (130).

15

20

6. Projection exposure system (100) according to Claim 5, wherein the scanning device (160) furthermore comprises a second deflection mirror (164), which is arranged between the reticle stage (130) and the second scanning mirror (162) and which is designed to direct the EUV radiation (400) that is being transmitted through the transmission reticle (1200) arranged in the reticle stage (130) at a substantially perpendicular angle with combined translation and tilting movements onto the second scanning mirror (162).

25

30

7. Projection exposure system (100) according to any of Claims 3 to 6,

35

wherein the combined translation and tilting movements of the mirrors (161, 162, 163, 164) of the scanning device (160) are coordinated with one another in such a way that substantially the same optical path length (OPL) for the EUV radiation (400) from the reticle stage (130) to the projection optical unit (140) results for each scanning position of the mirrors (161, 162, 163,

164).

8. Projection exposure system (100) according to any of the preceding claims,

5 wherein the projection lens (140) is designed to be telecentric at least on the input side.

9. Projection exposure system (100) according to any of the preceding claims,

10 wherein the projection exposure system (100) comprises a vacuum chamber (110) having a first partial chamber (111), which receives the illumination device (120), and a second partial chamber (112), which receives the projection lens (140), and at least one partition (114,
15 115) introducible between the illumination device (120) and the reticle stage (130) or between the projection lens (140) and the reticle stage (130) and serving for separating the two partial chambers (111, 112).

20 10. Projection exposure system (100) according to any of the preceding claims, furthermore comprising a damping device (170) for damping oscillatory movements of a transmission reticle (200) arranged in the reticle stage (130),
25 wherein the damping device (170) is designed to reduce the oscillatory movements of the transmission reticle (200) by blowing a gas on the transmission reticle (200) and/or by means of active acoustic or mechanical damping.

30

11. Projection exposure system (100) according to any of the preceding claims,
wherein an input mirror (141) of the projection lens (140) and/or a sectional plane (420, 430) arranged in
35 the beam path between the transmission reticle (200) and the input mirror (141) and parallel to the reticle plane (202) have/has a mirror-symmetrical and/or rotationally

symmetrical angle-of-incidence spectrum.

12. Transmission reticle (200) for an EUV lithography projection exposure system (100) according to any of the preceding Claims 1 to 11,
5 comprising a carrier layer (210) composed of a silicon-, germanium-, molybdenum, niobium- and/or zirconium-containing material and a structured absorber layer (220) arranged on the carrier layer (210).

13. Transmission reticle (200) according to Claim 12,
wherein the carrier layer (210) comprises a layer stack (211) composed of silicon and/or germanium layers separated from one another in each case by a zirconium silicide layer.
15

14. Transmission reticle (200) according to Claim 12 or 13,
wherein the absorber layer (220) is formed from a material containing nickel and/or tantalum nitride.
20

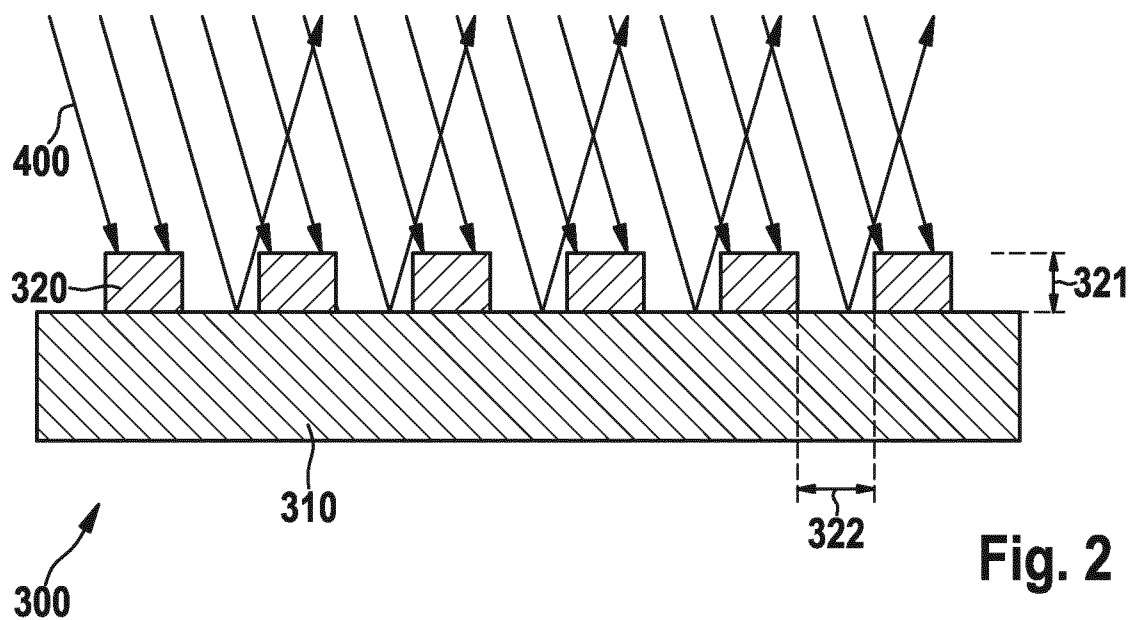
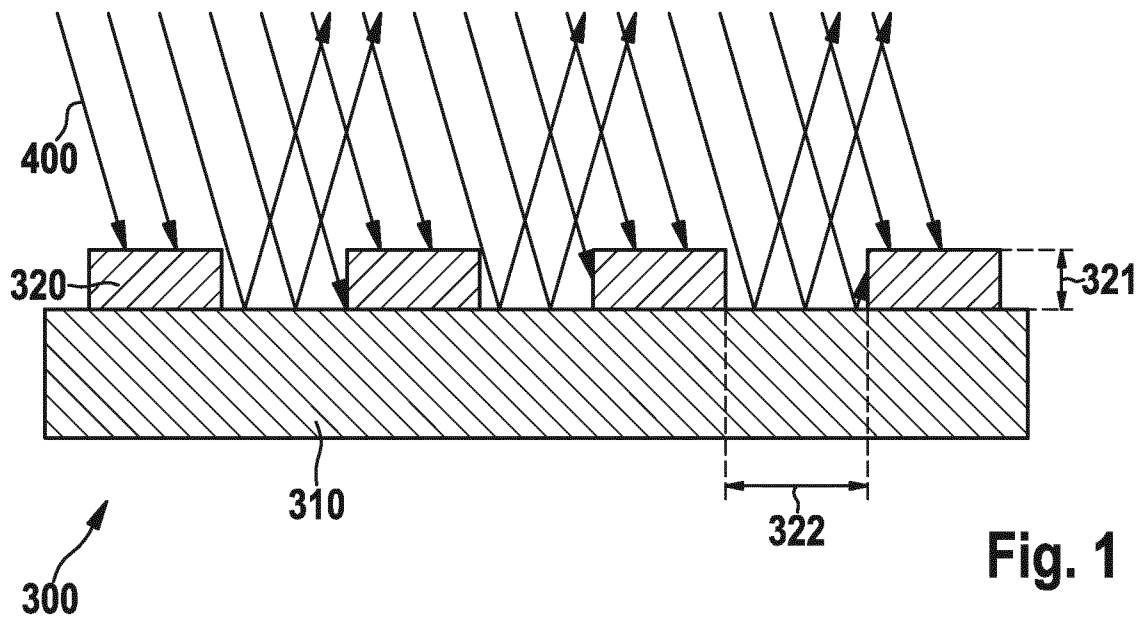
15. Transmission reticle (200) according to any of Claims 12 to 14,
wherein the carrier layer (210) is provided at least on one side with a protective layer (230) containing ruthenium, rhodium, carbon, iridium and/or silicon nitride (Si₃N₄).
25

16. Reticle arrangement (500) comprising a transmission reticle (200) according to any of Claims 12 to 15 and at least one pellicle (510) composed of a silicon-, germanium- and/or zirconium-containing material arranged in front of the transmission reticle (200).
30

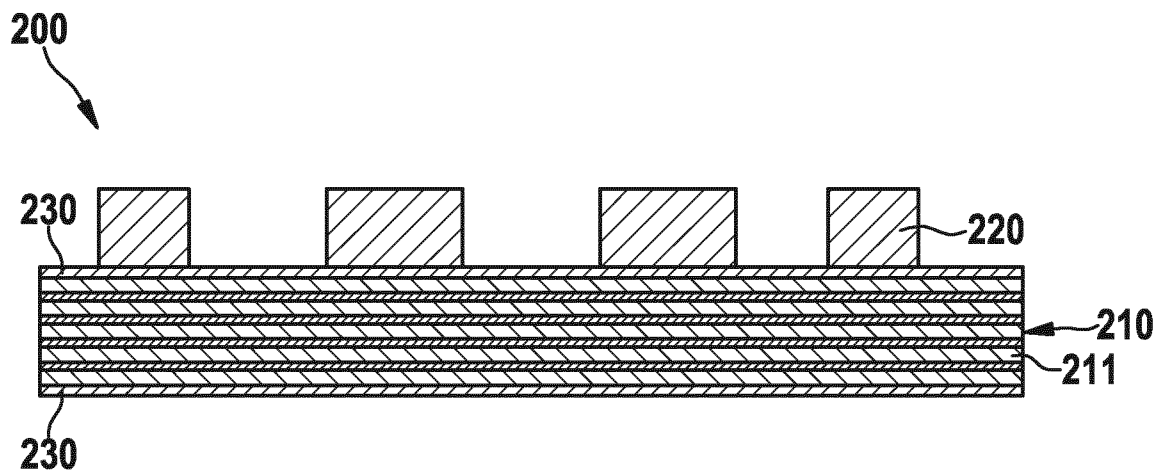
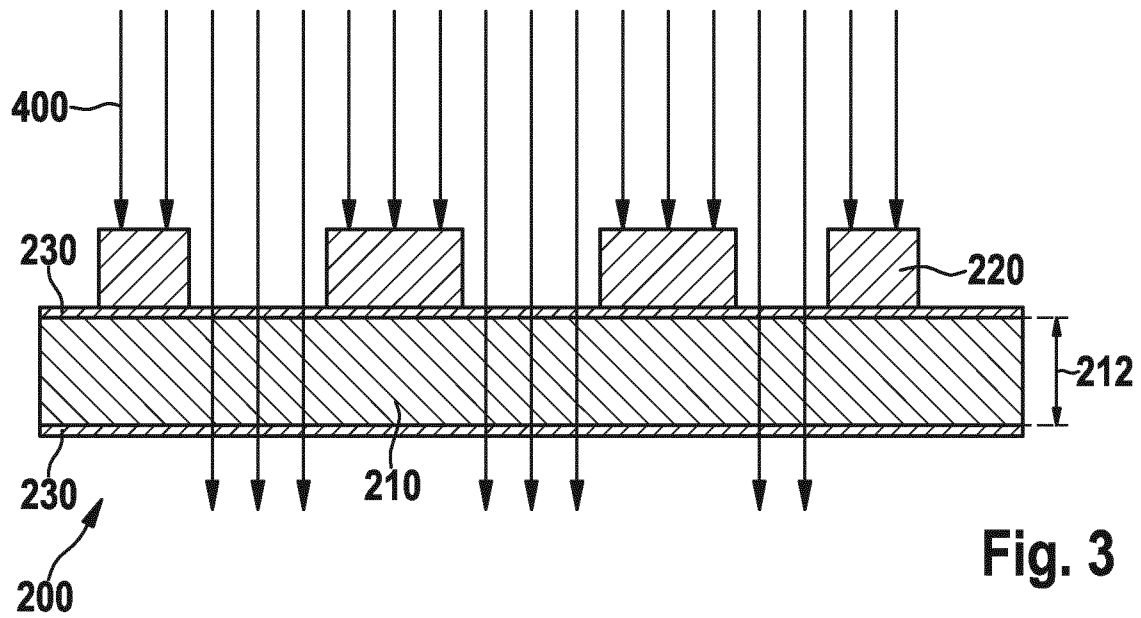
17. Reticle arrangement (500) according to Claim 16,
wherein the transmission reticle (200) and the pellicle (510) are enclosed by a common frame structure (520)
35

comprising at least one feed opening (521) for feeding gas into the interspace (530) between transmission retic-
cle (200) and pellicle (510).

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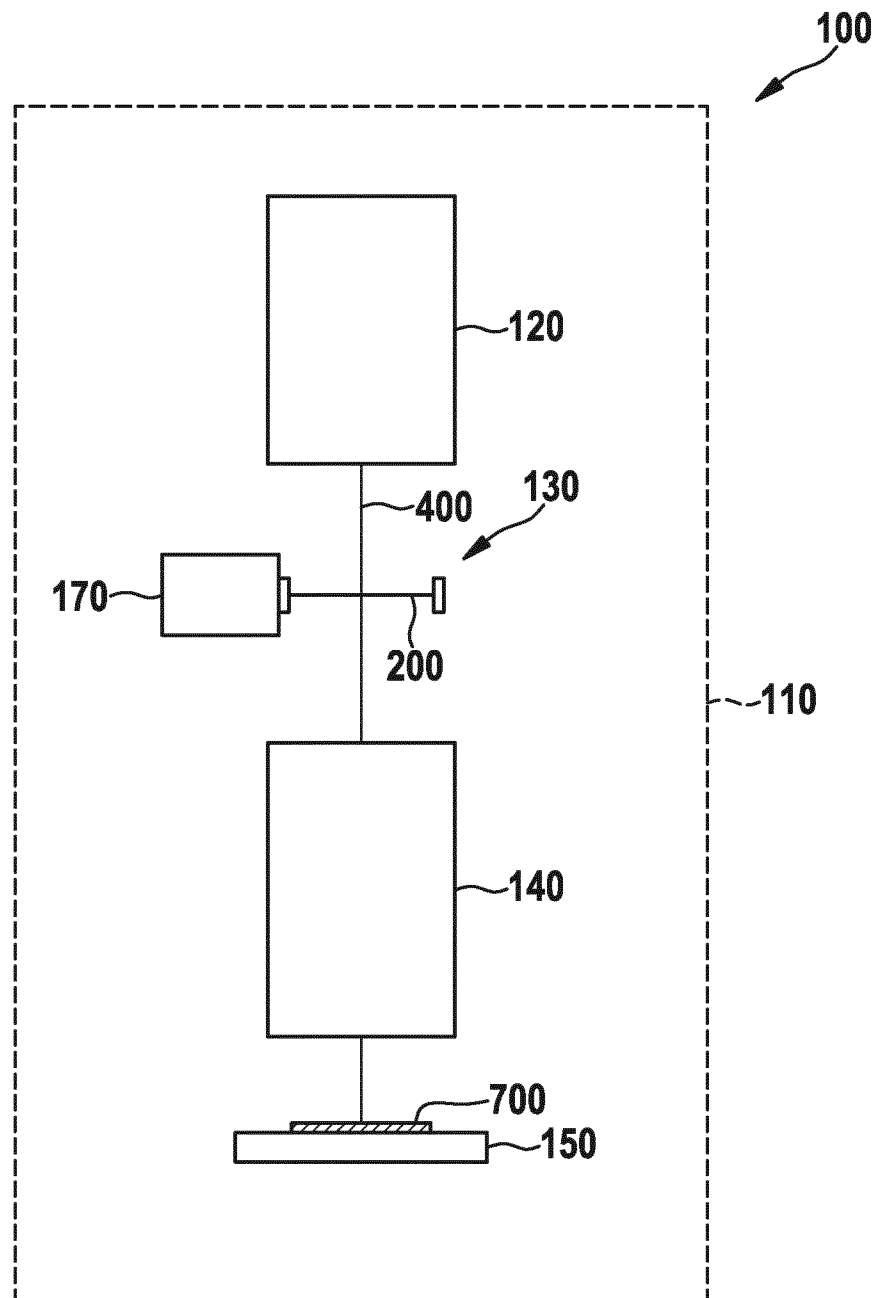


Fig. 5

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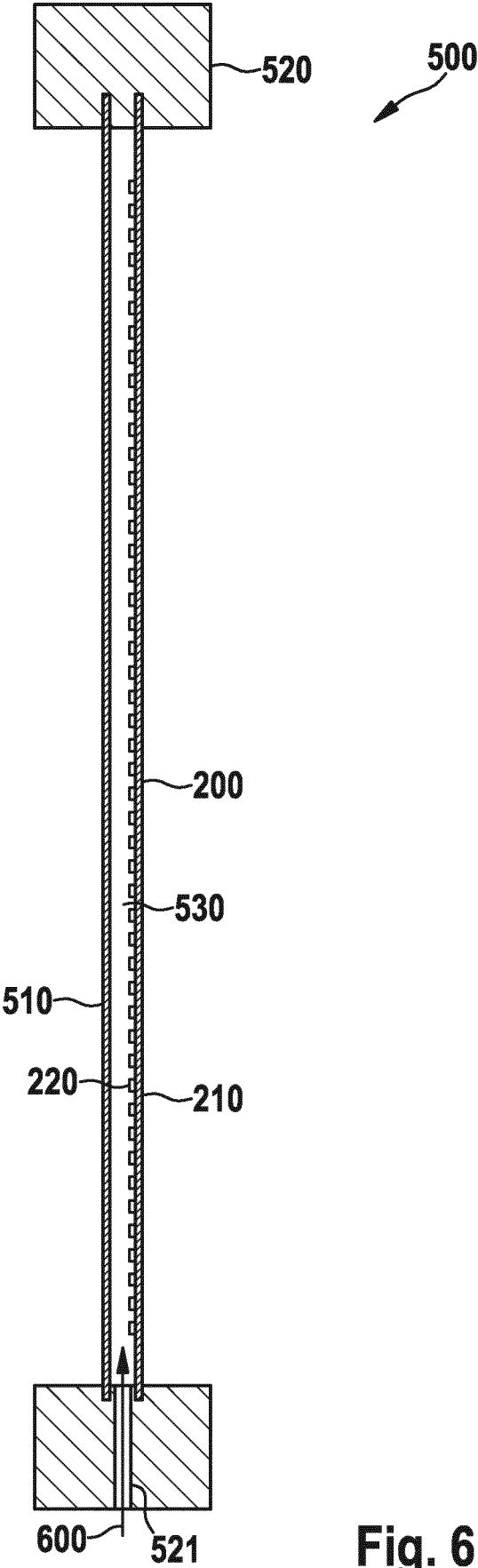


Fig. 6

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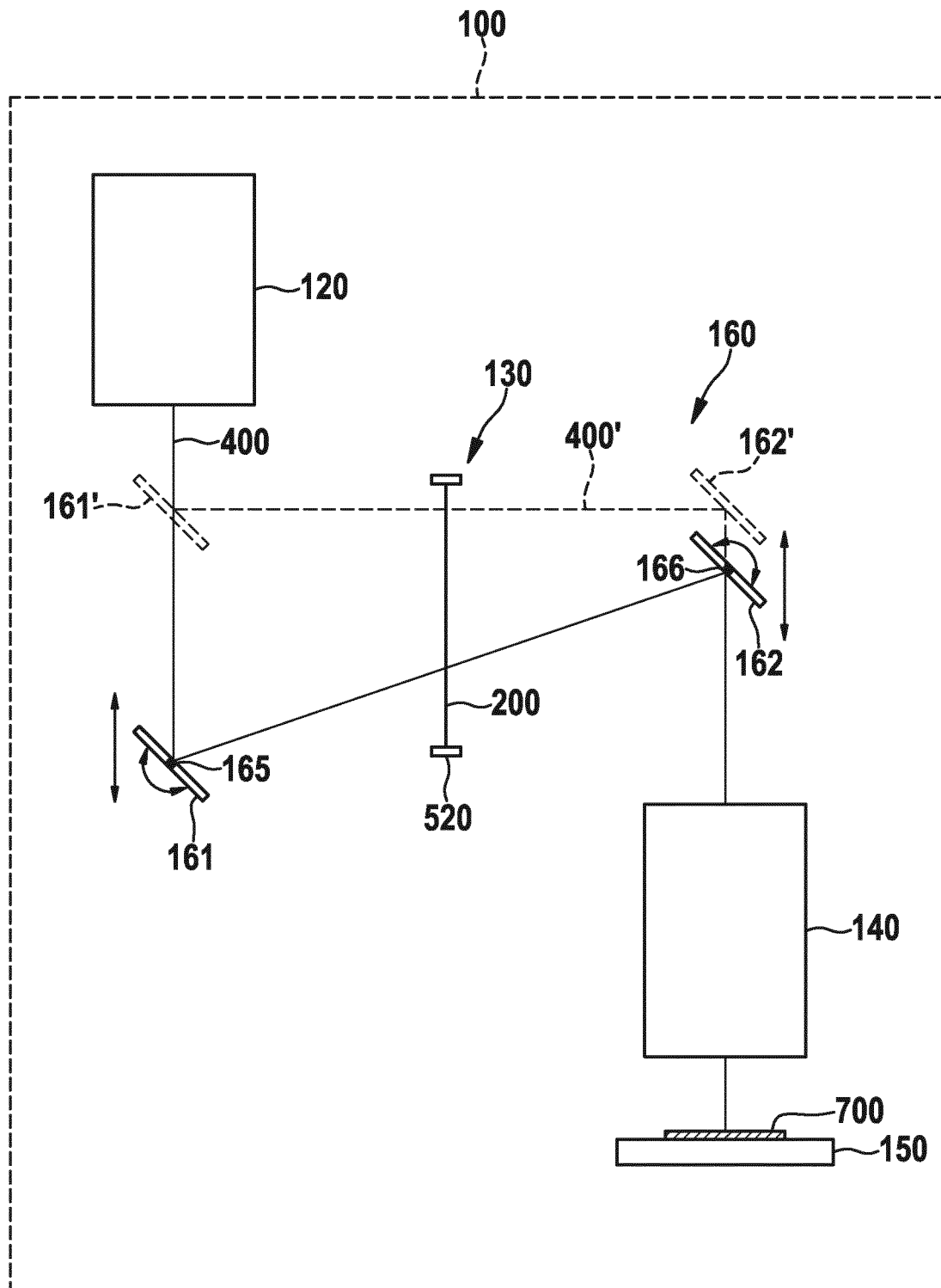


Fig. 7

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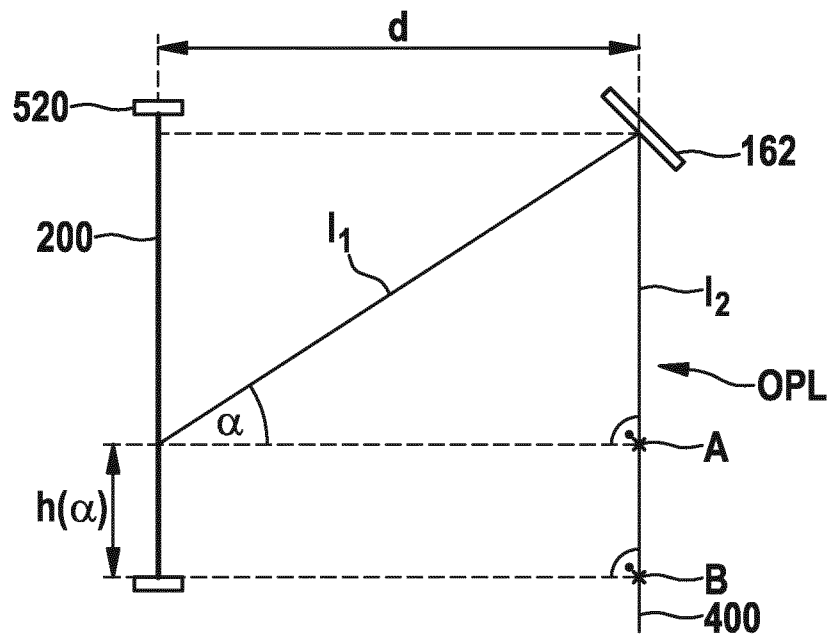


Fig. 8

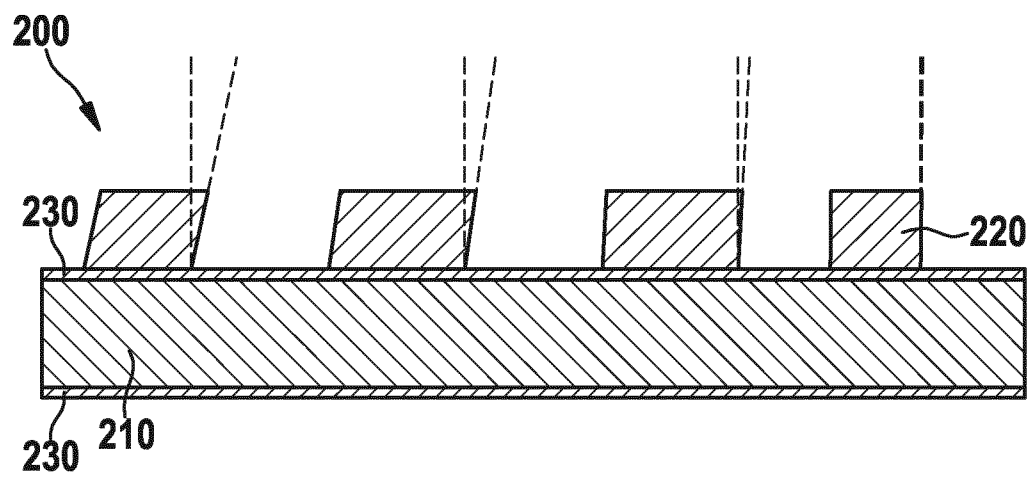


Fig. 9

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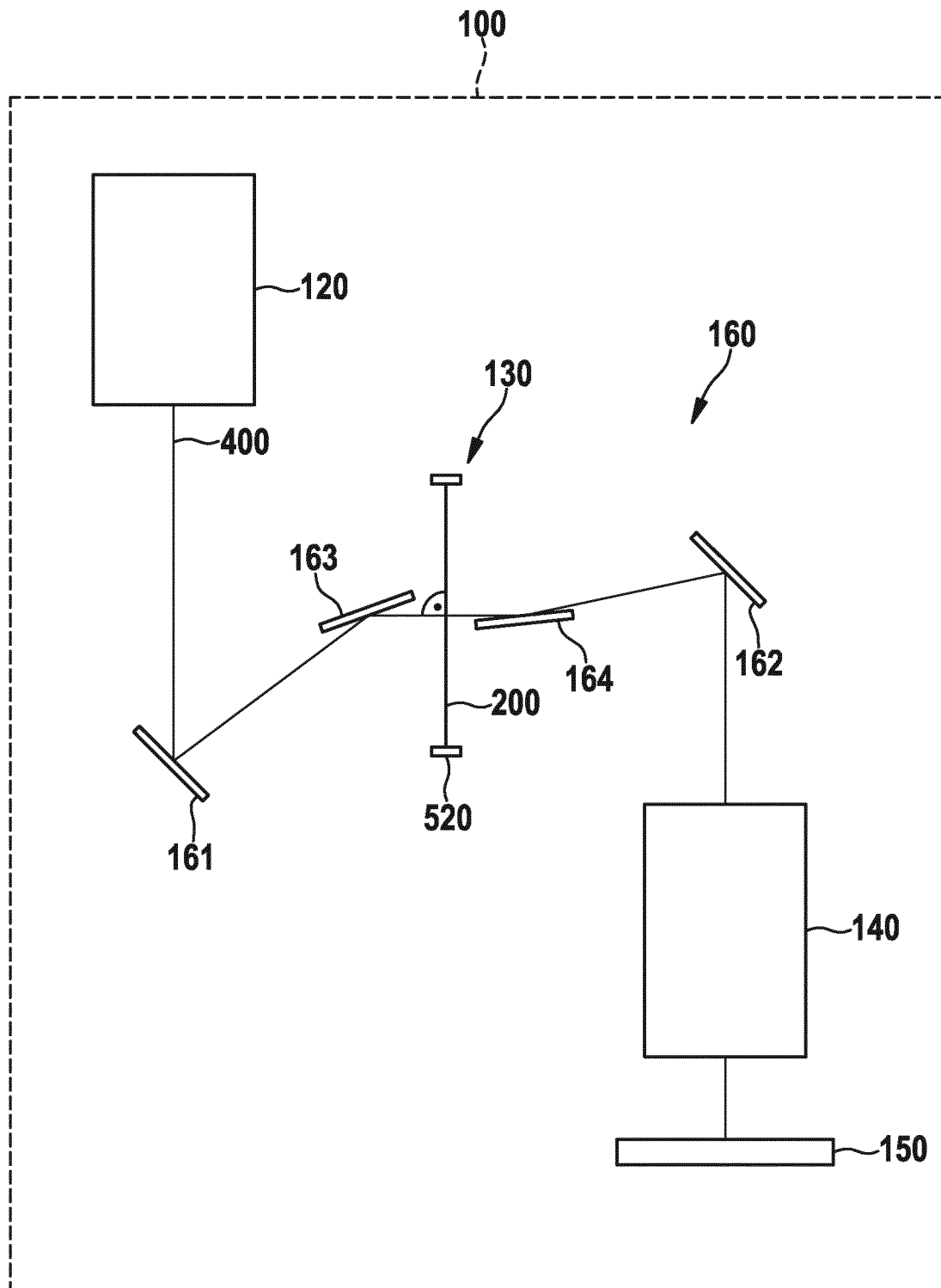


Fig. 10

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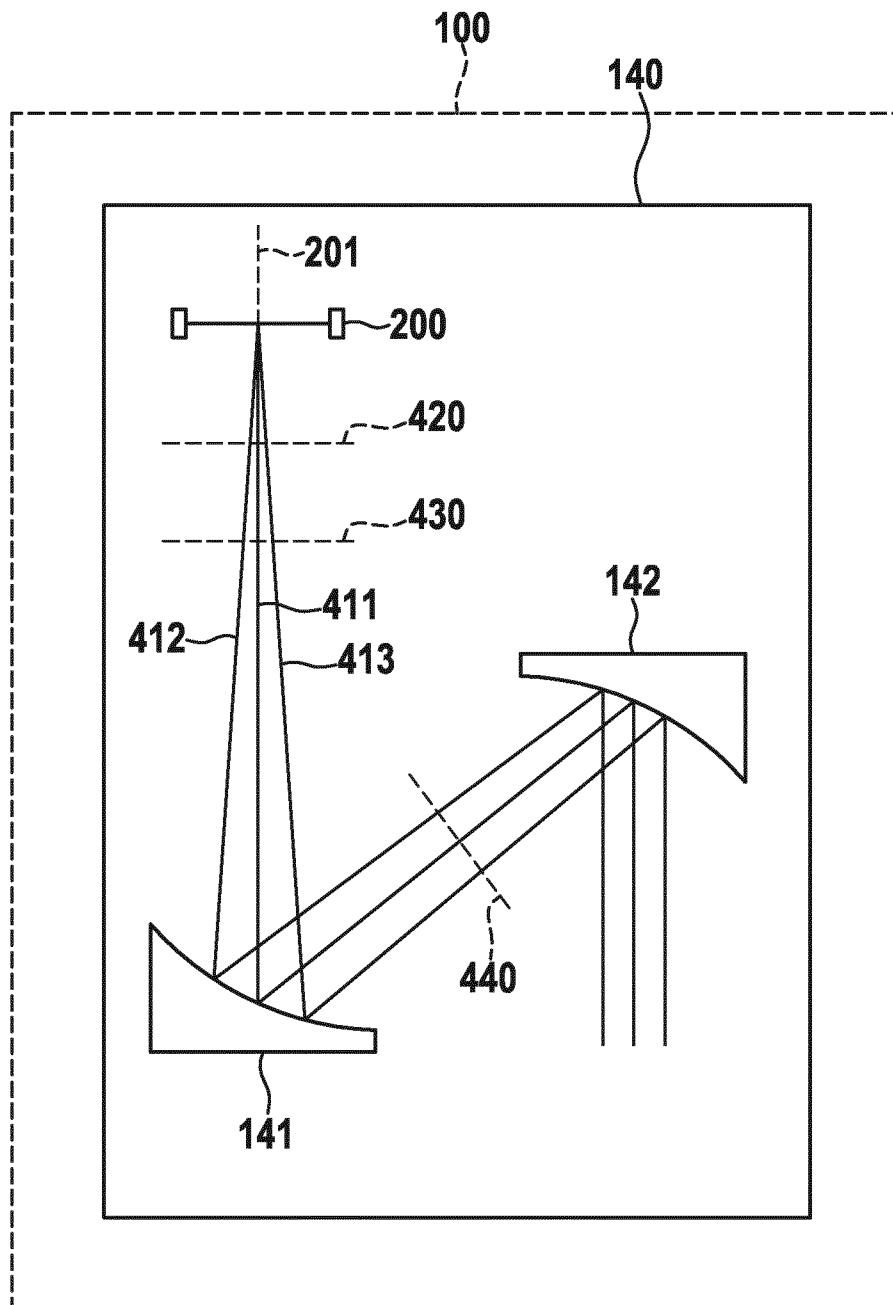


Fig. 11

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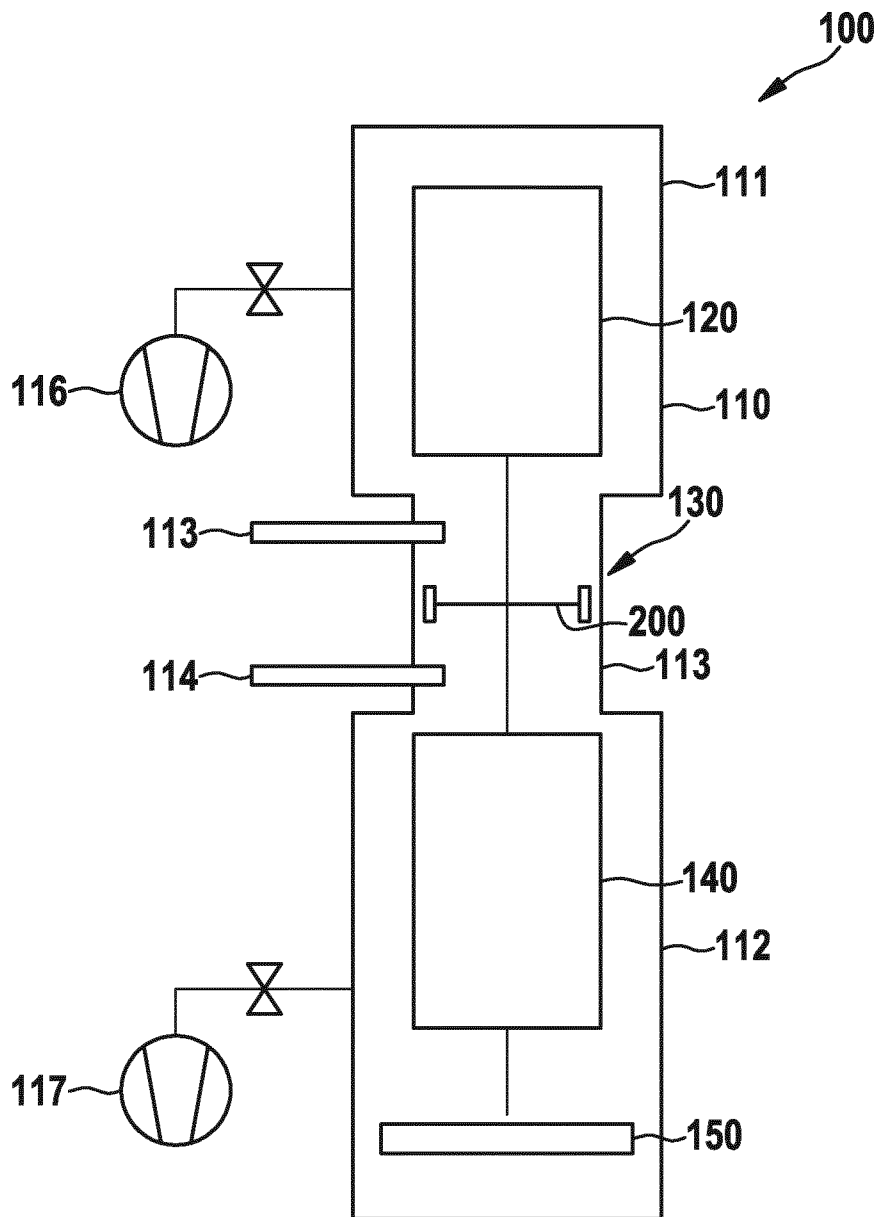


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/072335

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F1/22 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

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Y	paragraphs [0054] - [0075]; figure 11	1-4, 8-11,15, 17
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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

20 February 2014

Date of mailing of the international search report

03/03/2014

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INTERNATIONAL SEARCH REPORT

International application No
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