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(54) **METHOD FOR MANUFACTURING OF A PRE-ALIGNED X-RAY OPTICAL CORRECTION PLATE**

(57) It is described a method for manufacturing of an optical correction plate arrangement (13) comprising the steps of arranging a set of lenses (3) comprising at least a first lens (3a) and an optical correction plate arrangement holder (5) with respect to an optical axis (A) which coincides with a path of light. The set of lenses (3) is then aligned so that light impinging the set of lenses (3) on the first lens (3a) and leaving the set of lenses (3) is focused at a focal distance or an imaging distance. Afterwards, the aberrations of the set of lenses (3) are measured. An optical correction plate arrangement blank is positioned into the optical correction plate arrangement holder (5) in a default support position, wherein the optical correction plate arrangement blank comprises a substrate (15), wherein the substrate (15) comprises a photoactive coating (17). A region of the photoactive coating (17) which is aligned to the optical axis (A) is exposed

by the light before impinging the set of lenses (3) by the first lens (3a), by the light while travelling within the set of lenses (3) or by the light after leaving the set of lenses (3). After the exposure, the optical correction plate arrangement blank is transformed into an optical correction plate arrangement (13) based on the measured aberration, wherein a part of the optical correction plate arrangement (13) is adapted to at least partially compensate the aberrations of the set of lenses (3), wherein said part is aligned to the exposed region (19) of the substrate (15).

In addition, a lens box assembly (1) comprises a set of lenses (3) and an optical correction plate arrangement holder (5). Optical correction plate arrangement blanks and optical correction plate arrangement (13) may be re-inserted into the holder (5) with a high reproducible accuracy regarding their position.

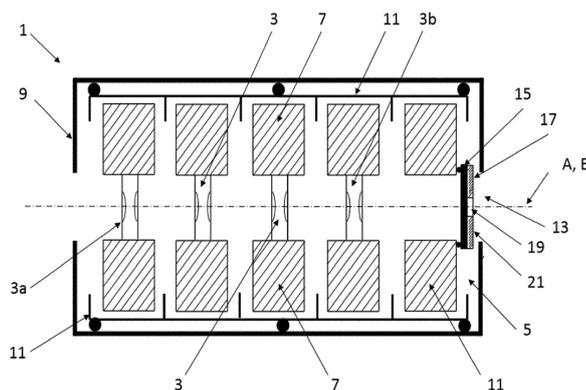


Fig. 1

Description

[0001] The present invention relates to a method for manufacturing an optical correction plate arrangement and a lens box assembly.

[0002] When using x-ray beams, e.g. from a synchrotron light source, focusing is a crucial but difficult task and requires special refractive lenses. Unfortunately, these refractive lenses typically have a large focal distance due to a limited refractive power of available materials, such as Be, Al, Si, Diamond, SU-8, PMMA. Hence, a single refractive x-ray lens is inconvenient for technical application. To still focus x-ray beams, a plurality of refractive lenses is arranged in a stacking arrangement, i.e. stacked behind each other while being aligned to a common optical axis. These stacks of lenses are so-called compound refractive lenses (CRL).

[0003] Many different materials and manufacturing techniques are known for the manufacturing of the components of CRLs. Examples of these techniques are Be and Al printing techniques or Si and diamond structuring techniques. All of these techniques, however, only allow the fabrication of imperfect refractive lenses due to imperfections of the manufacturing procedures themselves and limited material quality. As a consequence of these imperfections, the fabricated lenses show aberrations and lead to undesired blurring and broadening of the focal spot.

[0004] The aberrations of the CRLs can be characterized using ptychographic characterization of the focal spot as was demonstrated in A. Schropp et al, "Full spatial characterization of a nanofocused x-ray free-electron laser beam by ptychographic imaging", Scientific Reports 3, 1633 (2013). This characterization data is the starting point for computations which eventually lead to a phase shift pattern for aberration compensation and a corresponding structural pattern for a so-called phase plate which is manufactured according to the corresponding structural pattern.

[0005] A phase plate is typically the optical active part of an optical correction plate arrangement (OCPA). The phase plate is capable of correcting the aberration of the CRL. The phase plate may be positioned somewhere in the beam path going through the CRL, i.e. before the beam enters the CRL, while the beam travels through the CRL or after the beam leaves the CRL. A phase plate may be manufactured from amorphous SiO₂ or diamond or another suitable material using laser ablation technique, micro-milling or even 3D-printing techniques. For example, in case of laser ablation the laser removes material following a prior calculated pattern based on the ptychographic characterization. The surface pattern on the phase plate then leads to a phase shift of the outgoing x-ray beam leaving the CRL thereby compensating the aberration of the CRL and improving the focal spot.

[0006] However, a disadvantage of these phase plates as used in the prior art arises from the requirement of accurate alignment. The phase plate can only compen-

sate the aberration of the CRL, if it is properly aligned to the optical axis of the CRL. Such an alignment is highly time-consuming and costs precious beam time when used at commercial x-ray light sources.

[0007] It is therefore an object of the present invention to provide a method for manufacturing an optical correction plate arrangement and a lens box arrangement which overcome the problem of time-consuming alignment after the fabrication of the phase plate and prior to its use at the beamline.

[0008] This object is achieved in a first aspect of the invention by a method for manufacturing an optical correction plate arrangement (OCPA) according to claim 1. This method comprises the steps of

- arranging a set of lenses comprising at least a first lens and an optical correction plate arrangement holder with respect to an optical axis which coincides with a path of light,
- aligning the set of lenses so that light impinging the set of lenses on the first lens and leaving the set of lenses is focused at a focal distance or an imaging distance,
- measuring aberrations of the set of lenses,
- positioning an optical correction plate arrangement blank into the optical correction plate arrangement holder in a default support position, wherein the optical correction plate arrangement blank comprises a substrate, wherein the substrate comprises a photoactive coating,
- exposing a region of the photoactive coating aligned to the optical axis by the light before impinging the set of lenses by the first lens, by the light while travelling within the set of lenses or by the light after leaving the set of lenses, and
- transforming the optical correction plate arrangement blank into an optical correction plate arrangement based on the measured aberration, wherein a part of the optical correction plate arrangement is adapted to at least partially compensate the aberrations of the set of lenses, wherein said part is aligned to the exposed region of the substrate.

[0009] In other words, the method involves the following steps. At first, a set of lenses comprising at least a first lens and an OCPA holder are arranged with respect to an optical axis which coincides with a path of light. It may also be possible that the set of lenses comprises an aperture element. The purpose of the aperture element may be to clean the beam from undesired scattering. The cleaning may be achieved by choosing a suitable aperture of the aperture element by which the beam is manipulated. By this manipulation, the undesired scattering

is at least partially or fully removed.

[0010] Afterwards, the set of lenses is aligned so that light impinging the set of lenses on the first lens and leaving the set of lenses is focused properly at a focal distance. If the focal length is large compared to the distance to the source, the light leaving the set of lenses is alternatively focused on an imaging distance. Subsequently, the aberrations of the set of lenses are measured. This may be done, e.g., by studying the focal spot and subsequently retrieving the aberrations of the set of lenses by numerically propagating from the focal spot to the plane of lenses.

[0011] Afterwards, an OCPA blank is positioned into the OCPA holder in a default support position. The OCPA blank comprises a substrate and the substrate comprises a photoactive coating.

[0012] In a next step, a region of the photoactive coating aligned to the optical axis is exposed by the light before impinging the set of lenses by the first lens, by the light while travelling within the set of lenses or by the light after leaving the set of lenses. Finally, the OCPA blank is transformed into an OCPA based on the measured aberration. A part of the OCPA is adapted to at least partially compensate the aberrations of the set of lenses. This part is aligned to the exposed region of the substrate.

[0013] In the following, OCPA always refers to an optical correction plate arrangement which already comprises an optically active part, such as a phase plate, and which is ready to be used for compensating aberrations of a set of lenses. An OCPA blank is a precursor of an optical correction plate arrangement which has not yet an optically active part, but can be transformed into an OCPA, e.g., by the below described method steps.

[0014] In other words, according to the first aspect of the invention a set of lenses comprising at least a first lens, is arranged with respect to an optical axis coinciding with a path or a beam of light. In addition, a correction plate arrangement is arranged with respect to the at least one lens and its common optical axis. The correction plate arrangement is arranged either before the set of lenses, i.e. before the first lens, within the set of lenses or after the set of lenses when seen in a travelling direction of the light beam along a common optical axis of the first lens and the correction plate arrangement. The set of lenses may thereby form a compound refractive lens (CRL). The first lens is the lens on which a light beam impinges into the set of lenses. An OCPA holder is a holder which may hold an OCPA or an OCPA blank when inserted into the OCPA holder. The OCPA holder is adapted to provide and maintain a mechanically stable position of an OCPA blank or an OCPA. Both the set of lenses and the OCPA holder are aligned to the common optical axis. This common optical axis coincides with a path of a light beam. The sequence of positional arrangement of the set of lenses and the OCPA holder is such that light initially enters the first lens of the set of lenses, then leaves the set of lenses and propagates through the OCPA holder. It is also possible that the light initially prop-

agates through the OCPA holder along the common optical axis, then enters the first lens of the set of lenses and then leaves the set of lenses. It is, however, also possible that the light enters the first lens of the set of lenses, then propagates through the OCPA holder and then leaves the set of lenses.

[0015] In a next step, the set of lenses is aligned with respect to the optical axis. This means that the light impinging on the set of lenses, i.e. on the at least one first lens, and leaving the set of lenses is focused properly at the focal distance. It may also be possible that the light impinging on the first lens of the set of lenses and leaving the set of lenses is focused properly at the imaging distance if the focal length is large compared to the distance to the source.

[0016] Afterwards, the aberrations of the set of lenses are measured. This may be done, e.g., using typical ptychographic techniques as known in the art. The data may be processed and used for calculations of a physical pattern which compensates the aberration of the lenses. In other words, the aberrations may be determined by studying the focal spot and subsequently retrieving the aberrations of the set of lenses by numerically propagating from the focal spot to the plane of lenses.

[0017] Subsequently, an OCPA blank is positioned into the OCPA holder in a default support position. A default support position is a mechanically stable position of an OCPA blank or a usable OCPA which can be retrieved after removing and re-inserting the OCPA blank or OCPA into the OCPA holder with a high reproducible accuracy. The OCPA blank comprises a substrate having a photoactive coating. A substrate may be, e.g., a sheet of material which is adapted to carry a phase plate or which may form part of the phase plate itself. For the latter, the substrate preferably comprises Al, Be, Si, Diamond, amorphous SiO₂ and/or a polymer, e.g. on Si₃N₄. The photoactive coating may be any suitable photoactive coating which is reactive to X-ray radiation. The photoactive coating may comprise, e.g., a polymer, a metal, a metal-compound or any combination of the before mentioned. Preferably, the photoactive coating does not lead to or only imposes minimal contribution to the total aberrations of the light travelling through the photoactive coating. The total aberrations are the sum of the aberrations of the CRL and the photoactive coating. A minimal contribution to the total aberration by the photoactive coating is a contribution which may be less than, e.g., 10 % of a desired Strehl ratio of the corrected set of lenses.

[0018] Further on, a region of the photoactive coating on the substrate of the OCPA blank is exposed to the light following its beam path, by the light before impinging the set of lenses, i.e. impinging the first lens, by the light while travelling within the set of lenses or by the light after leaving set of lenses. In this context, exposed to light means that the light falls onto, or travels through the photoactive coating of the substrate of the OCPA blank. The energy deposited by the light into the photoactive coating leads to a reaction in the photoactive coating so that the

exposed region chemically or physically differs from the non-exposed region of the photoactive coating on the substrate. These two different regions may then be further processed by suitable methods.

[0019] Finally, the OCPA blank is transformed into an optical correction plate arrangement based on the measured aberration. This transformation of the OCPA may be performed in different ways. One possibility is to remove the exposed photoactive coating on the substrate and manufacture a phase plate onto the prior exposed region. However, it may also be possible to keep the photoactive coating in case any wavefront distortions caused by the photoactive coating are only small. For the manufacturing of the phase plate, the measured aberration data is used to compute a physical pattern which is fabricated onto the phase plate. The physical pattern leads to a spatially varying phase shift. This phase shift in turn compensates the aberration of the set of lenses. The fabrication of the phase plate may be done using suitable common deposition and/or ablation techniques as known in the art. Another possibility is to align a previously fabricated, i.e. a pre-fabricated, phase plate to the prior removed or kept exposed region of the substrate.

[0020] The method for manufacturing the OCPA according to the first aspect of the invention has the advantage that the optical active part, i.e. the phase plate, of the readily fabricated OCPA is automatically aligned to the light beam leaving the set of lenses, once the OCPA is inserted into the same OCPA holder. By using such a manufactured OCPA, the time-consuming alignment of the OCPA, or more specifically the time-consuming alignment of its phase plate, to the light beam leaving the set of lenses is avoided. Hence, costly beam time may be used for doing actual measurements rather than preparing the measurements thereby saving either beam time costs or time.

[0021] In a preferred embodiment according to the first aspect of the invention, the set of lenses comprises a final lens, wherein light leaves the set of lenses through the final lens. In other words, both first and final lens are part of the set of lenses. The final lens is stacked behind the first lens of the set of lenses when seen in a travelling direction of the light beam along the common optical axis. In addition, the first and final lens are arranged with respect to the optical axis which coincides with the path of light. The additional final lens improves the focusing abilities of the set of lenses.

[0022] In a preferred embodiment according to the first aspect of the invention, the step of transforming the optical correction plate arrangement blank into an optical correction plate arrangement comprises the steps of developing the photoactive coating thereby selectively removing material from the exposed region, and manufacturing a phase plate within the exposed region by removing and/or depositing or transferring material from/onto the exposed region, wherein the removal and/or deposition of material is based on the measured aberrations.

[0023] The removal and/or deposition of material are

selectively conducted and the resulting structural pattern on the substrate of the OCPA may be spatially varying over the area of the exposed region. One example for a removal technique is laser ablation. Basis for the removal and/or deposition of material is the measured aberration data which is used for computing a phase shift pattern and a corresponding structural pattern to be fabricated in the exposed region on the substrate thereby forming the phase plate. The physical pattern on the phase plate then leads to a spatially varying phase shift of the beam propagating through the phase plate. This phase shift in turn compensates the aberration of the set of lenses. This transforming step has the advantage that the phase plate is manufactured or transferred directly at/to the region through which the light beam will propagate when the OCPA is re-inserted into the OCPA holder. Hence, time-consuming alignment of a separate phase plate to the exposed region of the substrate is avoided.

[0024] In another preferred embodiment according to the first aspect of the invention, the step of transforming the optical correction plate arrangement blank into an optical correction plate arrangement comprises the steps of developing the photoactive coating, and mounting a pre-fabricated phase plate onto the substrate, wherein the pre-fabricated phase plate is aligned relative to the exposed region.

[0025] In this case the substrate with the developed photoactive coating serves both as an alignment frame and a carrier for the pre-fabricated phase plate. Since the OCPA blank is already aligned to the set of lenses by the exposed region, the pre-fabricated phase plate only needs to be aligned to the exposed region of the OCPA blank. This alignment may be done off-site, e.g., in a lab instead of in-situ at the beam line. An off-site alignment may be done as follows: an old phase plate is aligned to the lens stack in-situ at the beam line and exposed to the beam. Afterwards, the old phase plate may be used as a reference for further alignment of other phase plates in the lab. However, this procedure is more time consuming than the procedure of the invention.

[0026] However, a pre-fabricated phase plate may be aligned in situ at the beamline against the set of lenses. Afterwards, the pre-fabricated phase plate may be used as a reference for further alignments of other phase plates in the lab. Such an in situ alignment of a pre-fabricated phase plate involves the following steps:

1. Aligning the set of lenses with respect to the optical axis.

2. Inserting the previously fabricated optical correction plate into the beam. The previously fabricated optical correction plate may be arranged before, within or after the set of lenses along the path of the beam. The insertion may be done by a set of movement stages providing at least two axis of translation perpendicular to the optical axis, e.g. vertical and

horizontal, next to an OCPA blank.

3. Coarse aligning the optical correction plate. The goal of the coarse aligning step is to match the center of the OPCA with the beam axis. The coarse alignment is usually achieved by the use of a high resolution camera located downstream of the optical correction plate and the set of lenses.

4. Fine aligning the optical correction plate. The fine alignment of the optical correction plate requires a set of studies of aberrations of the set of lenses coupled with the optical correction plate. The optical correction plate is moved between scans to measure the aberration which may be typically small. The fine alignment is finished, when the measured aberrations are minimal. After the alignment is finished, the optical correction plate is fixed permanently to the OCPA blank.

[0027] The transforming step therefore reduces the efforts to be made in two ways: first, by requiring less beam time at the x-ray source facility, and second, by re-using prior fabricated phase plates which can still be used.

[0028] In a preferred embodiment according to the first aspect of the invention, the step of developing the photoactive coating comprises selectively removing material from an exposed region. The removal may, e.g., be chemically done. As an alternative, the removal may be done by optical techniques such as laser ablation.

[0029] In another embodiment according to the first aspect of the invention, the method further comprises a step of inserting the optical correction plate arrangement into the optical correction plate arrangement holder. By using the manufactured OCPA, the aberration of the light beam leaving the final lens can now be compensated thereby significantly improving the quality of the focus spot.

[0030] In a preferred embodiment according to the first aspect of the invention, after the step of inserting the optical correction plate arrangement in the optical correction plate arrangement holder the position thereof deviates in both directions perpendicular to the optical axis less than 5% of the lens physical aperture from the default support position. This range of positional tolerance allows to simply insert the OCPA into the OCPA holder and use it without any further lengthy alignment of the OCPA and its holder with respect to the beamline.

[0031] In a further preferred embodiment according to the first aspect of the invention, the aberrations of the set of lenses are measured using ptychography. Ptychography is a well suited technique for studying the aberration of a set of lenses and may easily be performed.

[0032] In another preferred embodiment according to the first aspect of the invention, the light beam is formed of coherent, partially coherent or incoherent monochromatic x-rays.

[0033] In another preferred embodiment according to the first aspect of the invention, the monochromaticity of

the x-rays is in the range of $10e-2$ to $10e-5 \Delta\lambda/\lambda$. This monochromaticity allows to conduct studies using a defined energy range as well as a known wavelength range of the x-rays.

5 **[0034]** In a second aspect of the invention, the above object is achieved by the lens box assembly according to claim 9.

[0035] The lens box assembly comprising a set of lenses having at least a first lens, arranged on an optical axis, and an optical correction plate arrangement holder, wherein the set of lenses and the optical correction plate arrangement holder are arranged with respect to the same optical axis, wherein the first lens is adapted to be impinged by light, wherein the lens box assembly comprises fastening means for fastening the set of lenses and the optical correction plate arrangement holder in the lens box assembly, wherein the optical correction plate arrangement holder is configured to receive and support either an optical correction plate arrangement blank or an optical correction plate arrangement in a default support position, and wherein a position of an optical correction plate arrangement blank and/or optical correction plate arrangement in the optical correction plate arrangement holder after the optical correction plate arrangement blank and/or optical correction plate arrangement is inserted, removed and inserted back into the optical correction plate arrangement holder corresponds in both directions perpendicular to the optical axis to the default support position.

30 **[0036]** In a preferred embodiment according to the second aspect of the invention, wherein the set of lenses further comprises a final lens, wherein the set of lenses is adapted to be left by light through the final lens which is the second lens, wherein the first lens and the final lens are stacked behind each other along the optical axis, and further comprising aligning means adapted to align the at least first lens of the set of lenses with respect to the other at least one lens in order to focus a light beam leaving the set of lenses. In other words, both first and final lens are part of the set of lenses. The final lens is stacked behind the first lens of the set of lenses when seen in a travelling direction of the light beam along the common optical axis. In addition, the first and final lens are arranged with respect to the optical axis which coincides with the path of light. The additional final lens improves the focusing abilities of the set of lenses.

45 **[0037]** In a preferred embodiment according to the second aspect of the invention, the position of the optical correction plate arrangement blank and/or optical correction plate arrangement after reinsertion into the optical correction plate arrangement holder deviates in both directions perpendicular to the optical axis less than 5 % of the lens physical aperture, preferably less than 3 % from the default support position.

55 **[0038]** In other words, the lens box assembly comprises a set of lenses having at least a first lens, preferably at least a first and a final lens. It may also be possible that the set of lenses comprises an aperture element.

This purpose of the aperture element may be to clean the beam from undesired scattering. The cleaning may be achieved by choosing a suitable aperture of the aperture element by which the beam is manipulated. By this manipulation, the undesired scattering is at least partially or fully removed. Furthermore, an OCPA holder is added to the set of lenses, e.g. preferably arranged behind the final lens, following the positional order of the first lens, final lens and the OCPA holder. However, it may also be possible that the OCPA holder is arranged anywhere between the first lens and the final lens along the beam path. All lenses and the OCPA holder are aligned along the same optical axis. The lens box assembly further comprises fastening means which fasten the set of lenses and the OCPA holder in the lens box assembly. In addition, the lens box assembly comprises aligning means which allows an individual alignment of each lens of the set of lenses with respect to the other lenses to achieve a minimal sized focus spot for the light beam leaving the last lens. The OCPA holder is configured to support an OCPA blank and/or an OCPA which is inserted into the OCPA holder in a default position. A default support position is a mechanically stable position of an OCPA blank or an OCPA which can be retrieved after removing and re-inserting the OCPA blank or OCPA into the OCPA holder with a high reproducible accuracy. This means that the position of an OCPA blank and/or OCPA after inserting it into the OCPA holder, removing it from the OCPA holder and re-inserting it into the OCPA holder, the OCPA holder preferably deviates in both directions transversal to the optical axis of the set of lenses less than 5% of the lens physical aperture, preferably less than 3% from the default support position.

[0039] By using a lens box assembly according to claim 11, an OCPA may easily be manufactured by the method of claim 1. This means that at first an OCPA blank is inserted into the lens box assembly, then exposed to the light, externally transformed into an OCPA and then re-inserted into the lens box assembly thereby being immediately aligned with the optical axis and the light beam leaving the final lens from the set of lenses. Hence, no lengthy re-alignment to the optical axis is required and precious beam time is saved.

[0040] The invention will hereinafter be further elucidated with reference to a drawing of an exemplary embodiment of a lens box assembly according to the invention, wherein

Figure 1 shows a cross sectional view of the embodiment of the lens box assembly;

[0041] Figure 1 shows a cross sectional view of an embodiment of a lens box assembly 1. The lens box assembly 1 comprises a set of four lenses 3 suitable for x-ray beams, preferably for monochromatic x-ray beams, having a first lens 3a, a final lens 3b and intermediate lenses 3 there between thereby forming a compound refractive lens (CRL). However, it could also be possible that the

lens box assembly only comprises a single lens. The x-ray beams may be coherent, partially coherent or incoherent monochromatic x-rays. However, common CRL typically may comprise a number of lenses in the range of 100 individual lenses, even though the CRL in Fig. 1 only depicts four lenses.

[0042] The lenses 3 in Fig. 1 are stacked behind another along an optical axis A. The optical axis A coincides with a central axis of a light beam B along its beam path. Furthermore, an optical correction plate arrangement (OCPA) holder 5 is arranged behind the final lens 3b and aligned to the same optical axis A. The first lens 3a is the lens 3 on which a light beam B impinges, the final lens 3b of the stacked lenses 3 is the lens 3 from which the light beam B leaves the set of lenses 3. However, the OCPA holder 5 may also be arranged at any other position along the beam path and/or the optical axis A, within or after the CRL. For example, it is also possible that the light initially propagates through the OCPA holder 5 along the common optical axis A, then enters the first lens 3a of the set of lenses 3 and then leaves the final lens 3b. In that case, the beam axis position is defined by the aperture situated before the first lens 3a. It is, however, also possible that the light enters the first lens 3a of the set of lenses 3, then propagates through the OCPA holder 5 and then leaves the final lens 3b of the set of lenses 3.

[0043] The lens box assembly 1 further comprises fastening means 7 for fastening the lenses 3 and the OCPA holder 5 to a housing 9 of the lens box assembly 1. In addition, aligning means 11 are provided in the lens box assembly 1 for aligning each lens 3 with respect to the other lenses 3 in order to focus a light beam leaving the final lens 3b.

[0044] The OCPA holder 5 comprises an OCPA 13 manufactured according to the method of claim 1. The OCPA holder 5 is configured to support an OCPA blank and/or an OCPA 13 in a default support position. In this preferred embodiment, the position of an OCPA blank or the OCPA 13 in the OCPA holder 5 and hence in the housing 9 after a sequence of inserting, removing and re-inserting the OCPA 13 back into the OCPA holder 5 deviates in both directions perpendicular to the optical axis A less than 5% of the lens physical aperture, preferably less than 3% from the default support position.

[0045] The OCPA 13 in the OCPA holder 5 is manufactured as described in the following. Initially, the lenses 3 are individually aligned to each other and with respect to the optical axis A in order to achieve an optimal focusing of the light beam B.

[0046] Afterwards, the aberrations of the lenses 3 are measured. This may be done, e.g., using typical ptychographic techniques as known in the art. This measurement data is the basis for a pattern of a phase plate which compensates the aberration of the lenses 3. In other words, the aberrations may be determined by studying the focal spot and subsequently retrieving the aberrations of the set of lenses 3 by numerically propagating from the focal spot to the plane of the lenses 3.

[0047] Subsequently, an OCPA blank is positioned into the OCPA holder 5 in a default support position. A default support position is a mechanically stable position of an OCPA blank or an OCPA 13 which can be retrieved after removing and re-inserting the OCPA blank or OCPA 13 into the OCPA holder 5 with a high reproducible accuracy. The OCPA blank comprises a substrate 15 having a photoactive coating 17. A substrate 15 may be a sheet of material which is adapted to carry a phase plate or which may form the phase plate itself. For the latter, the substrate 15 preferably comprises Silicon nitride, Be, Al, Diamond, Si, SU-8, and/or amorphous SiO₂. The photoactive coating 17 may be any suitable photoactive coating 17 which is reactive to X-ray radiation. The photoactive coating 17 may comprise, e.g., a polymer, a metal, a metal-compound or any combination of the before mentioned. Preferably, the photoactive coating 17 does not have a or only imposes minimal contribution to the total aberrations of the light travelling through the photoactive coating 17. The total aberrations are the sum of the aberrations of the set of lenses 3, i.e. the CRL, and the photoactive coating 17. A minimal contribution to the total aberration by the photoactive coating 17 is a contribution which is less than 10 percent of a desired Strehl ratio of the corrected set of lenses.

[0048] Further on, a region 19 of the photoactive coating 17 on the substrate 15 of the OCPA blank is exposed to the light beam B which is, e.g. leaving the last and final lens 3b. In this context, exposing to light beam B means that the light beam B falls onto or travels through the photoactive coating 17 of the substrate 15 of the OCPA blank. The energy deposited by the light beam B into the photoactive coating 17 leads to a reaction in the photoactive coating 17 so that the exposed region 19 chemically or physically differs from the non-exposed region 21 of the photoactive coating 17 on the substrate 15. These two different regions 19, 21 may then be further processed by suitable methods.

[0049] Finally, the OCPA blank is transformed into a usable OCPA 13. This transformation may for example be done in two different ways. One possibility of transforming the OCPA blank into a usable OCPA 13 comprises the step of developing the photoactive coating 17 thereby selectively removing material from the exposed region 19. However, it is also possible that the exposed photoactive coating 17 is kept but transformed into a different physical state using suitable method. This transformation may be preferred in case the photoactive coating 17 only gives a minimal contribution to the total aberration.

[0050] Subsequently, a phase plate is manufactured within the exposed region 19. The manufacturing is done by removing and/or depositing material from/into the exposed region 19. In this context, a typical technique used for removing material is, e.g., laser ablation. The removal of material is a selective removal and/or deposition and may be spatially varying over the area of the exposed region 19. Basis for the removal of material is the meas-

ured aberration data which is used for computing a phase shift pattern and a corresponding structural pattern. The corresponding structural pattern is fabricated in the exposed region 19 on the substrate 15 thereby forming the phase plate.

[0051] Another possibility of transforming the OCPA blank into an OCPA 13 involves a step of developing the photoactive coating 27 and removing material from the exposed region 19. Subsequently a pre-fabricated phase plate is mounted onto the substrate 15. This pre-fabricated phase plate is aligned relative to the exposed region 19.

[0052] Due to the exposed region 19 already being aligned to the optical axis A, the usable OCPA 13 is also automatically aligned when inserted into the OCPA holder 5.

Claims

1. Method for manufacturing of an optical correction plate arrangement (13) comprising the steps of:
 - arranging a set of lenses (3) comprising at least a first lens (3a) and an optical correction plate arrangement holder (5) with respect to an optical axis (A) which coincides with a path of light,
 - aligning the set of lenses (3) so that light impinging the set of lenses (3) on the first lens (3a) and leaving the set of lenses (3) is focused at a focal distance or an imaging distance,
 - measuring aberrations of the set of lenses (3),
 - positioning an optical correction plate arrangement blank into the optical correction plate arrangement holder (5) in a default support position, wherein the optical correction plate arrangement blank comprises a substrate (15), wherein the substrate (15) comprises a photoactive coating (17),
 - exposing a region of the photoactive coating (17) aligned to the optical axis (A) by the light before impinging the set of lenses (3) by the first lens (3a), by the light while travelling within the set of lenses (3) or by the light after leaving the set of lenses (3), and
 - transforming the optical correction plate arrangement blank into an optical correction plate arrangement (13) based on the measured aberration, wherein a part of the optical correction plate arrangement (13) is adapted to at least partially compensate the aberrations of the set of lenses (3), wherein said part is aligned to the exposed region (19) of the substrate (15).
2. Method for manufacturing of an optical correction plate arrangement (13) according to claim 1, wherein the set of lenses (3) comprises a final lens (3b), wherein light leaves the set of lenses (3) through the

- final lens (3b).
3. Method for manufacturing of an optical correction plate arrangement (13) according to claim 1 or 2, wherein transforming the optical correction plate arrangement blank into an optical correction plate arrangement (13) comprises the steps of
 - developing the photoactive coating (17) thereby selectively removing material from the exposed region (19), and
 - manufacturing a phase plate within the exposed region (19) by removing and/or depositing material from/onto the exposed region (19), wherein the removal and/or deposition of material is based on the measured aberrations.
 4. Method for manufacturing of an optical correction plate arrangement (13) according to claim 1 or 2, wherein transforming the optical correction plate arrangement blank into an optical correction plate arrangement (13) comprises the steps of
 - developing the photoactive coating (17), and
 - mounting a pre-fabricated phase plate onto the substrate (15), wherein the pre-fabricated phase plate is aligned relative to the exposed region (19).
 5. Method for manufacturing of an optical correction plate arrangement (13) according to claim 4, wherein the step of developing the photoactive coating (17) comprises selectively removing material from an exposed region (19).
 6. Method for manufacturing of an optical correction plate arrangement (13) according to any one of claim 1, 2, 4 or 5, wherein the method further comprises the step of
 - inserting the optical correction plate arrangement (13) into the optical correction plate arrangement holder (5).
 7. Method for manufacturing of an optical correction plate arrangement (13) according to any one of the preceding claims, wherein after inserting the optical correction plate arrangement (13) in the optical correction plate arrangement holder (5) the position thereof deviates in both directions perpendicular to the optical axis (A) less than 10 percent of the lens aperture from the default support position.
 8. Method for manufacturing of an optical correction plate arrangement (13) according to any one of the preceding claims, wherein the aberrations of the set of lenses (3) are measured using ptychography.
 9. Method for manufacturing of an optical correction plate arrangement (13) according to any one of the preceding claims, wherein the light beam (B) is formed of coherent, partially coherent or incoherent monochromatic x-rays.
 10. Method for manufacturing of an optical correction plate arrangement (13) according to claim 9, wherein the monochromaticity of the x-rays is in the range of $10e-2$ to $10e-5 \Delta\lambda/\lambda$.
 11. Lens box assembly (1),
 - comprising a set of lenses (3) having at least a first lens (3a), arranged on an optical axis (A), and an optical correction plate arrangement holder (5), wherein the set of lenses (3) and the optical correction plate arrangement holder (5) are arranged with respect to the same optical axis (A),
 - wherein the first lens (3a) is adapted to be impinged by light,
 - wherein the lens box assembly (1) comprises fastening means (7) for fastening the set of lenses (3) and the optical correction plate arrangement holder (5) in the lens box assembly (1),
 - wherein the optical correction plate arrangement holder (5) is configured to receive and support either an optical correction plate arrangement blank or an optical correction plate arrangement (13) in a default support position, and
 - wherein a position of an optical correction plate arrangement blank and/or optical correction plate arrangement (13) in the optical correction plate arrangement holder (5) after the optical correction plate arrangement blank and/or optical correction plate arrangement (13) is inserted, removed and inserted back into the optical correction plate arrangement holder (5) corresponds in both directions perpendicular to the optical axis (A) to the default support position.
 12. Lens box assembly (1),
 - wherein the set of lenses (3) further comprises a final lens,
 - wherein the set of lenses (3) is adapted to be left by light through the final lens (3b) which is the second lens,
 - wherein the first lens (3a) and the final lens (3b) are stacked behind each other along the optical axis (A), and
 - further comprising aligning means (11) adapted to align the at least first lens (3a) of the set of lenses (3) with respect to the other at least one lens (3) in order to focus a light beam (B) leaving the set of lenses (3).

13. Lens box assembly (1) according to claim or 12, wherein the position of the optical correction plate arrangement blank and/or optical correction plate arrangement (13) after reinsertion into the optical correction plate arrangement holder (5) deviates in both directions perpendicular to the optical axis (A) less than 10 percent of the lens aperture from the default support position.

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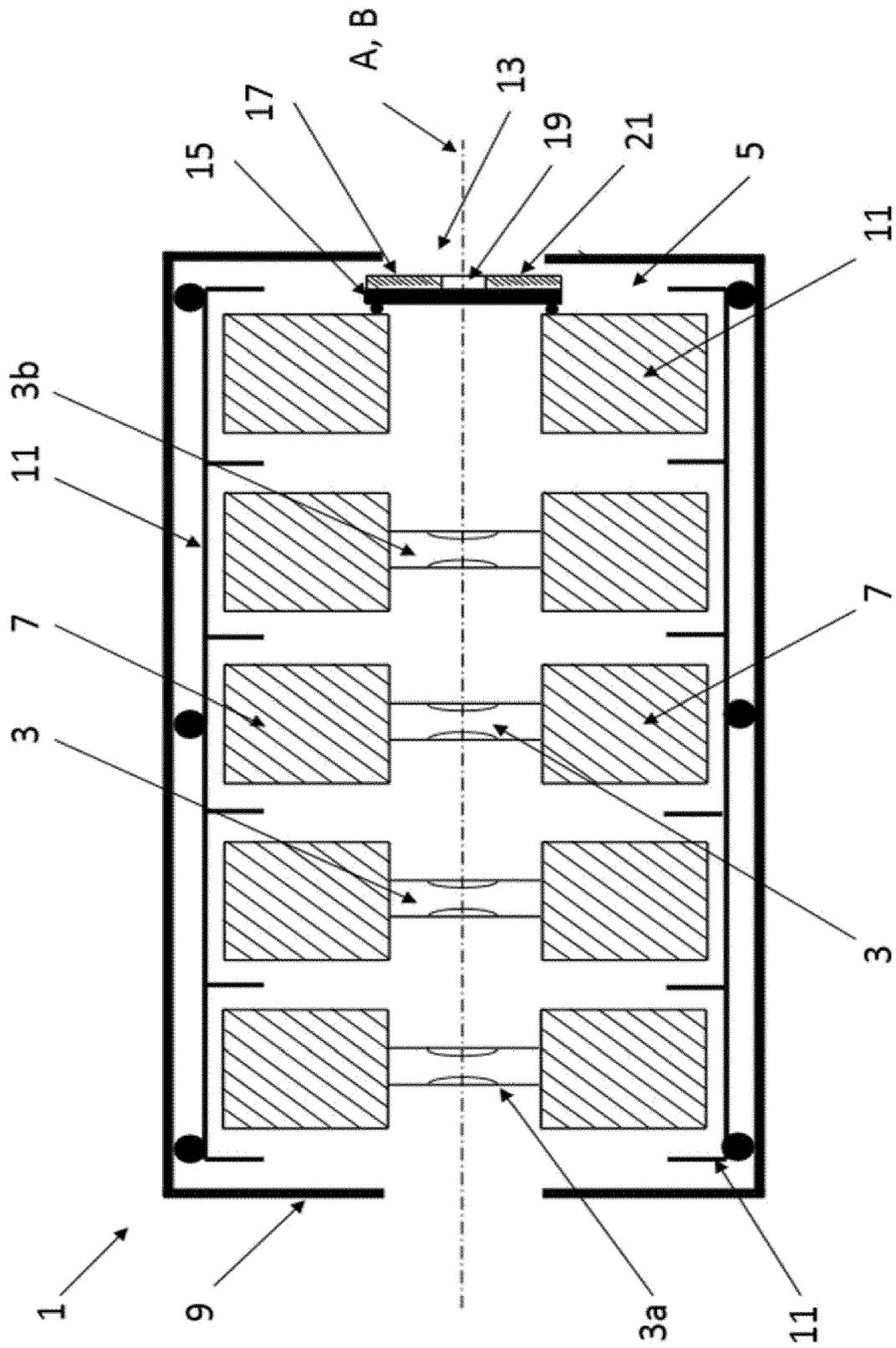


Fig. 1



EUROPEAN SEARCH REPORT

Application Number
EP 18 16 2404

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 1 024 522 A1 (NIKON CORP [JP]) 2 August 2000 (2000-08-02)	11-13	INV. G21K1/06 G03F7/00 G21K7/00
A	* figs 1 - 3 and the description thereof * * fig 9 and the description thereof * * paragraph [0066] * * paragraph [0120] - paragraph [0122] *	1	
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Place of search		Date of completion of the search	Examiner
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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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