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(71) **Applicant** (for all designated States except US): **CARL ZEISS SMT GMBH** [DE/DE]; Rudolf-Eber-Str. 2, 73447 Oberkochen (DE).

(72) **Inventors; and**

(75) **Inventors/Applicants** (for US only): **SÄNGER, Ingo** [DE/DE]; Wangenmühle 4, 89522 Heidenheim (DE). **SCHLESENER, Frank** [DE/DE]; Nelkenweg 2, 73447 Oberkochen (DE).

(74) **Agents: WEGNER, Hans** et al.; Bardehle Pagenberg, Partnerschaft Patentanwälte Rechtsanwälte, Prinzregentenplatz 7, 81675 München (DE).

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(54) **Title:** APPARATUS AND METHOD FOR COMPENSATING A DEFECT OF A CHANNEL OF A MICROLITHOGRAPHIC PROJECTION EXPOSURE SYSTEM

Fig. 7
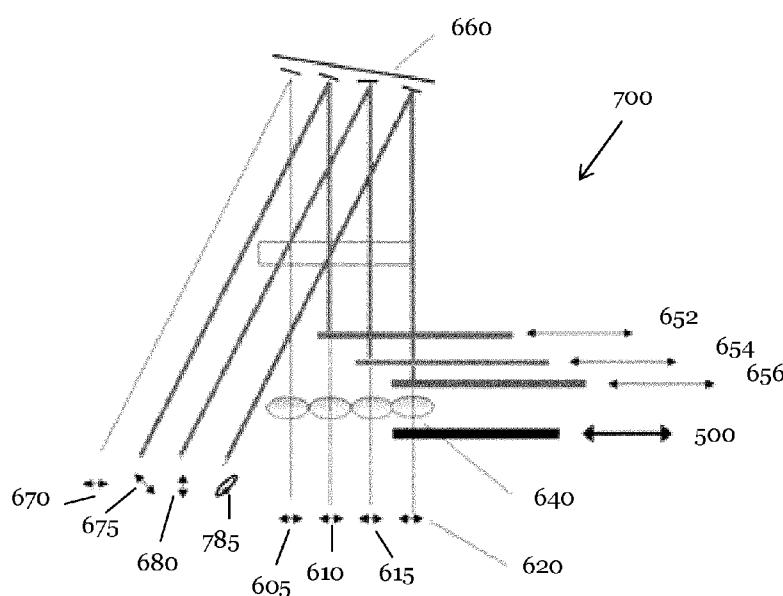
(57) **Abstract:** The invention relates to an illumination system of a microlithographic projection exposure apparatus comprising (a) a plurality of channels, each channel guiding a partial beam and at least one channel comprising at least one defect, and (b) at least one optical element arranged within the at least one channel having the at least one defect, the optical element being adapted to at least partially compensate the at least one defect of the partial beam of the channel.

Apparatus and method for compensating a defect of a channel of a microlithographic projection exposure system

1.   Field of the invention

The present invention relates to the field of compensating a defect of a channel of a microlithographic projection exposure system.

2.   Background of the invention

Microlithographic projection exposure systems are used for the production of microstructured components, in particular semiconducting components such as integrated circuits (ICs). A microlithographic projection exposure system comprises as essential components a light source, an illumination device or illumination system and a projection objective or a projection system. In modern projection exposure systems which use electromagnetic radiation of the deep ultraviolet (DUV) wavelength range, the light source is typically an excimer laser system (a krypton fluoride (KrF) excimer laser for the 248 nm, an argon fluoride (ArF) laser for the 193 nm, or a fluoride (F2) excimer laser for the 157 nm wavelength).

The properties of the illumination system determine the imaging quality and the wafer throughput which can be achieved with the microlithographic projection exposure system. The illumination system has to be capable of forming a light beam from the light source for various possible illumination modes or settings. Various settings as for example an annular field illumination and/or dipole or quadrupole off-axis illuminations having different degrees of coherence are used for generating an optimal imaging contrast of the structure elements of the photolithographic mask in the photosensitive layer arranged on a substrate. At the same time, the projection exposure system has to have a reasonable pro-

cess window. For example, off-axis oblique illuminations can be used in order to increase the depth of focus (DoF) by means of a two-beam interference and also to increase the resolving power of the overall system.

5   The illumination system has to generate the various settings with the highest efficiency as the effort and cost drastically increase for the generation of electromagnetic radiation with decreasing wavelength, in particular in the DUV wavelength range. Furthermore, it is mandatory that the optical intensity distribution is as uniform as possible across the illumi-

10   nation mode since any inhomogenity reduces the critical dimension (CD) of the feature elements which are to be imaged on a substrate.

In order to fulfil these requirements, the optical beam of the light source is separated or split into a number of partial beams which are individual-

15   ly shaped and/or directed in various channels by micro-structured optical components within the optical illumination system. Microlithographic illumination systems which use different principles for splitting and guiding the partial beams are for example disclosed in the US 2004 / 0 108 167 A1 and the WO 2005 / 026 843 A2.

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The term "channel" means here and in the following a volume within the illumination system through which a partial beam travels from the location where it is generated by splitting of the input beam to the location where it is superimposed or combined with other partial beams.

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The projection objective of the microlithographic projection exposure system collects the light transmitted through the mask and focusses it onto a photosensitive layer or photoresist dispensed on a substrate which is arranged in the focus plane of the projection objective. The sub-

30   strate is often a semiconducting wafer, as for example a silicon wafer.

As a result of the constantly increasing integration density in the semiconductor industry, photolithographic projection exposure systems have to project smaller and smaller structures onto the photoresist. In order

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to fulfil this demand, as already mentioned, the exposure wavelength of projection exposure systems has been shifted from the near ultraviolet across the mean ultraviolet into the deep ultraviolet region of the electromagnetic spectrum. Presently, a wavelength of 193 nm is typically used for the exposure of the photoresist on wafers. As a consequence, the manufacturing of microlithographic projection exposure systems with increasing resolution is becoming more and more complex, and thus more and more expensive as well. In the future, projection exposure systems will use significantly smaller wavelengths in the extreme ultraviolet (EUV) wavelength range of the electromagnetic spectrum (e.g. in the range of 10 nm - 15 nm).

At a given wavelength the resolution of a projection exposure system can be augmented by increasing the numerical aperture (NA) of its projection system. M. Totzeck et al. discuss in the article "Polarization influence on imaging", J. Microlith., Microlab., Microsyst., 4(3) (Jul-Sep 2005), p. 031108-1 – 031108-15) that for high NA projection systems the polarization of the illumination beam has a significant influence on the resolution of a projection exposure system.

Therefore, in order to be able to control the degree of coherence of the optical beam exiting a microlithographic illumination system, it is necessary to control its polarization state. Various approaches are already known for adjusting a predetermined polarization distribution in the pupil plane and/or in the mask plane of the illumination system as well as in the projection system in order to optimize the image contrast. Some not exhaustive examples are listed in the following: WO 2005/069081 A2, WO 2005/031467 A2, US 6 191 880 B1, US 2007/0146676 A1, WO 2009/034109 A2, WO 2008/019936 A2, WO 2009/100862 A1, EP 1 879 071 A2, and DE 10 2004 011 733 A1

The documents mentioned above describe a control of the polarization of the overall beam or of some sub-beams comprising many partial beams of individual channels of the illuminations system. On the other hand,

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there may be defects as for example polarization defects of individual partial beams caused by defective or weak optical components within individual channels. The superposition of partial beams where one or several partial beams may have a changed or even an indefinite polarization state can lead to an unpredictable polarization state of the overall beam. This situation results in a reduction of the intensity in preferred state (IPS) which may fall below a predetermined threshold.

It is therefore one object of the present invention to provide an apparatus and a method for compensating defects of partial beams within the channel of the partial beams.

3. __Summary of the invention__

According to a first aspect of the invention, a method according to patent claim 1 is provided. In an embodiment, an illumination system of a microlithographic projection exposure apparatus comprises (a) a plurality of channels, each channel guiding a partial beam and at least one channel comprising at least one defect, and (b) at least one optical element arranged within the at least one channel having the at least one defect, the optical element being adapted to at least partially compensate the at least one defect of the partial beam of the channel.

By compensating a defect within a channel of a partial beam, it is avoided that the local defect of a partial beam may deteriorate the quality of the beam formed by a superposition of several of the partials beams exiting the illumination system to illuminate the mask. In particular, the superposition of several well behaved partial beams and a single defective partial beam may result in an impairment of a second quantity of the overall optical beam exiting the illumination system. Such an impairment may lead to complex correction measures for the illumination beam(s) of an illumination system.

Since the optical element only minimally affects the beam characteristics

of the partial beam in the respective channel, the insertion of the optical element does not require compensative measures for the partial beam. On the other hand, the compensation of the defect effectively increases the intensity in preferred state (IPS) of the beam(s) exiting the illumination system.

In a further aspect, the at least one defect comprises a variation of the polarization of the partial beam in the at least one channel. In another aspect, the at least one optical element at least partially compensates the at least one defect by modifying a polarization of the partial beam.

One example of a defect in a channel of an illumination system is a variation of the polarization of the partial beam. Sources for such a polarization variation may be reflection and/or transmission at interfaces and coatings and/or a birefringence of optical components in the channel of the optical beam. Birefringence may be intrinsic or material birefringence and/or may be induced by a strain caused by the mounting of the optical component. By selectively modifying the polarization of a partial beam, the variation of the polarization can at least partially be compensated.

According to a further aspect, the at least one optical element comprises a strain induced birefringence which at least partially compensates the variation of the polarization of the partial beam. In another beneficial effect, the strain induced birefringence comprises introducing at least one arrangement of local persistent modifications in an area of the optical element outside of its optically relevant area.

It is well known that the introduction of a local deformation in a transparent material causes a local strain induced birefringence variation. Based on a model which describes an induced local deformation as a function the parameters of the laser beam used for the introduction of the local deformation, the strain distribution which is locally induced in a material of an optical element can be controlled. Therefore, a prede-

termined local strain distribution can be introduced in the optical element. This strain distribution results in a respective birefringence distribution.

In a preferred embodiment, one or several arrangements of local persistent modifications are introduced in an area of the optical element which is optically not relevant. The far reaching strain components extend in the optically relevant area of the optical element and cause a strain induced birefringence distribution which at least partially compensates the optical defect in the respective channel. The arrangement of local persistent modifications can be calculated from the required birefringence distribution with the aid of a computer system.

The configuration in which the arrangement(s) of local persistent modifications are introduced in an area outside of the optically relevant area of the optical element has the advantage that the arrangement of local persistent modifications cannot have an impact on photons of the partial beam. Moreover, the arrangement of local persistent modifications cannot degrade the optical properties of the optically relevant area of the optical element.

The term "essentially" means in this description a variation of a quantity which is below the resolution limit of state of the art measurement technique.

The optically relevant area of an optical element is the area through with a beam or a partial beam traverses the optical element or from which a beam or a partial beam is reflected. The optically not relevant area is given by all other area portions of the optical element.

In a further aspect, a mirror of a two-dimensional mirror array directs a partial beam passing through the at least one optical element in an outer edge of a pupil in agreement with a predetermined target pupil.

The retardation caused by the birefringence shows a symmetrical varia-
tion across the beam within the pupil plane. It increases from the pupil
centre toward the pupil edge. Thus, by directing the partial beam or the
partial beams traversing the at least one optical element and thus having

5   acquired a defined retardation toward the pupil edge, the retardation in
the pupil edge can be compensated. This process has to take the con-
straint into account that the intensity distribution in the pupil plane has
to fulfil a predetermined target distribution. However, it is not necessary
that the defect in the pupil plane comprises a symmetric variation across

10   the pupil in order to be compensated in the defined illumination system.

According to a further beneficial aspect, the strain induced birefringence
of the at least one optical element comprises a fast axis having a fixed
direction.

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Introducing a strain induced birefringence in the optical element having
a fast axis with a fixed direction allows a space-resolved correction of the
polarization variation.

20   In another aspect, the strain induced birefringence of the at least one
optical element comprises a retardation in the optical relevant area of
the at least one optical element of 1 nm - 10 nm, preferably 2 nm - 8 nm,
and most preferably 3 nm - 6 nm.

25   In another preferred aspect, the at least one optical element maximizes a
modification of the polarization of the partial beam by selecting an orien-
tation of the fast axis of the at least one optical element with respect to a
polarisation of the partial beam in the channel.

30   The described optimization process is easily performed if the partial
beam has a linear polarization and the optical element has a fast axis
with a fixed direction. However, the defect compensation can also be
performed if the partial beam has an arbitrary polarization and the
strain induced birefringence does not generate a fixed fast axis.

In another beneficial aspect, the illumination system is adapted to superimpose partial beams of at least one first channel and at least one second channel in a single spot, so that the retardation of the superimposed partial beams compensates the retardation of the illumination system.

This feature is advantageous as it allows compensating defects of several channels whose partial beams superimpose in a single spot to form an illumination beam exiting the illumination system by inserting a specifically designed optical element in one of the channels of the partial superimposed beams. Consequently, the defect compensation of a multitude of channels where some or all of the channels have a defect is simplified to a large extent.

In a further aspect, the polarization of the partial beam of the at least one first channel is rotated by a predetermined amount with respect to the polarization of the partial beam of the at least one second channel.

According to a further aspect, the compensation of the at least one defect increases an intensity in preferred state of a beam exiting the illumination system.

The intensity in preferred state (IPS) is an important characteristic for the imaging quality of a projection exposure system. The IPS is therefore defined by a threshold value (e.g. IPS > 97 %) which restricts the loss of usable photons to a very low percentage.

In another aspect, the at least one optical element is adapted to comprise an actuator to induce strain in the optically relevant area of the at least one optical element. In a further aspect, the actuator comprises a piezo-electric element.

By combining the optical element with an actuator, a temporarily changing strain can be applied to the optical element which allows a rapid ad-

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aptation of the birefringence to a new situation. The actuator may change the retardation leaving the fast axis untouched, or it may be arranged to modify both, the orientation of the fast axis and the retardation. It is also conceivable to arrange two or more actuators to the optical

5   element.

According to another aspect, the at least one optical element is adapted to be dynamically inserted in the at least one channel during an operation of the illumination system.

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This feature enables an optimization of the IPS of the projection exposure system during its operation. It requests that the optical element does neither essentially vary the optical intensity of the partial beam nor change its phase relationship.

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In still a further aspect, the at least one optical element comprises a multitude of optical elements being fabricated with different fixed fast axes and/or different amounts of retardations.

20   For example, there may be defects in a channel of a microlithographic illumination system having various amounts of material birefringence. Therefore, it may be favourable to generate optical elements having various arrangements of local persistent modifications which are adapted to the different defects occurring in the channels of the illumination sys-

25   tem.

According to another aspect, the multitude of optical elements is adapted to be inserted in a multitude of channels each one having a defect so that the intensity in preferred state of a beam exiting the illumination system

30   is maximized.

The microlithographic illumination system has a multitude of channels. Therefore, it is possible that more than one channel has a defect. The defect in two or more channels may have essentially the same defect

amount or the defects of the different channels may have different defect amounts. These defects can be compensated by inserting optical elements in the respective defective channels which best compensate the respective defect. The defect compensation is controlled by the IPS of the

5   superimposed partial beams.

In another aspect, the at least one optical element is adapted to comprise a polarizer which changes the polarization of the partial beam by a predetermined amount.

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By introducing an arrangement of local persistent modifications in an area optically not used by the polarizer, the polarizer can perform a predetermined polarization manipulation at the partial beam and can simultaneously compensate a defect caused by a polarization variation with-

15   in the channel. Such a configuration may save space in the channels of the microlithographic illumination system.

In a further aspect, the at least one optical element comprises a mirror for reflecting the partial beam. According to yet another aspect, the at

20   least one optical element comprises a lens for deflecting the partial beam.

As already mentioned, a micolithographic illumination system typically comprises many different channels each one guiding a partial beam.

25   Consequently, there is often less space between the various partial beams. It may therefore be beneficial to combine the defect compensation with a further function of an optical element in order to save space in the illumination system.

30   It is also conceivable to combine the just discussed approach with the insertion of one or more optical elements specifically designed for the defect compensation in a channel. It can be beneficial to add a predetermined amount of defect compensation to optical elements of the specific channels as for example channels close to the edges and/or corners

of the channel matrix and insert additional optical elements only to a few channels having a specific defect.

According to another aspect, the at least one optical element is adapted to comprise at least one plate having at least two optically relevant areas for at least two channels, the optically relevant areas are arranged between areas of the at least one plate which are optically not relevant.

As the channel arrangement of a microlithographic illumination system typically comprises many channels, there may be situations in which it is cumbersome to individually compensate defects in a number of channels. This approach of the defect compensation of individual channels may be limited due to space restrictions if a number of adjacent channels of the channel arrangement have a defect. Therefore, it may be useful to generate a plate which can compensate defects of a number of channels.

In still another aspect, the at least two optically relevant areas are arranged in a one-dimensional row or a two-dimensional rectangular matrix, the at least two optically relevant areas have a diameter which is adjusted to a diameter of the partial beams, and the at least two optically relevant areas have a distance which is adjusted to a distance between the partial beams of the at least two different channels.

In a further aspect, the plate comprises at least one optically relevant area being adapted to at least partially compensate the at least one defect and at least one optical relevant area not having a strain induced birefringence.

Similar to an optical element for a single channel, a plate may integrate various functions as for example defect compensation and generating a predetermined polarization variation.

In still another aspect, the plate comprises at least two optically relevant areas being adapted to compensate at least two different defects.

According to a further aspect, the at least two optically relevant areas of the plate comprise a polarizer which change the polarization of the partial beam by a predetermined amount.

In yet another aspect, ultra-short laser pulses are used to introduce the at least one arrangement of local persistent modifications.

In a further beneficial aspect, the plate is adapted to be moved and/or to be rotated essentially perpendicular to the beam directions of the at least two partial beams.

Similar to an optical element for a single channel, this feature enables an optimization of the defect compensation by adjusting the plate to a position within the channel matrix at which the IPS loss is minimized.

According to another aspect, the plate is adapted to be dynamically inserted in a beam path of the partial beams of the least two channels during the operation of the illumination system.

In still a further advantageous aspect, a method for compensating at least one defect in at least one channel of an illumination system of a microlithographic projection exposure system uses an illumination system of any of the above described aspects.

Finally, another aspect further comprises the step of inserting at least one optical element in at least one channel having a defect which is best compensated by the at least one optical element.

4.   Description of the drawings

In order to better understand the present invention and to appreciate its practical applications, the following figures are provided and referenced

hereafter. It should be noted that the figures are given as examples only and in no way limit the scope of the invention.

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Fig. 1   schematically presents essential components of a microlithographic projection exposure system;

Fig. 2   schematically shows a cross-section of a channel arrangement of a microlithographci illumination system;

10   Fig. 3   illustrates a distribution of a retardation of an illumination system of a DUV projection exposure system of a linearly polarized optical beam analysed in the plane of the photolithographic mask, Fig. 3a reproduces a left portion, Fig. 3b presents a centre portion, and Fig. 3c indicates a right portion of

15   the field of view of the focus plane of the illumination system;

Fig. 4   schematically represents a block diagram of an apparatus for introducing an arrangement of local persistent modifications

20   in an optical element;

Fig. 5   schematically illustrates an optical element having an optically relevant area and an optically not relevant area into which arrangements of local persistent modifications are in-

25   troduced;

Fig. 6   schematically represents a cut-out of Fig. 2, wherein polarization plates are inserted in the partial beams of various channels;

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Fig. 7   shows Fig. 6 where an optical element is arranged in one of the channels in order to vary the polarization of the respective partial beam;

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Fig. 8   schematically illustrates that the retardations of two super-
            imposed partial beams are additive;

Fig. 9   schematically depicts a plate having an arrangement of 4 x 4
            optically relevant areas for a matrix of 4 x 4 partial beams,
            wherein some of the optically relevant areas have different
            arrangements of local persistent modifications to cause a
            strain induced birefringence having different orientations of
            the fast axis and different amounts of retardation;

Fig. 10   schematically shows the plate of Fig. 9 having four different
            configurations of strain induced birefringence of optically
            relevant areas wherein each configuration has different ori-
            entations of their fast axes and different amounts of retarda-
            tion;

Fig. 11   schematically represents the combination of three polariza-
            tion plates and a first compensation plate in a portion of the
            channel matrix;

Fig. 12   schematically shows the combination of three polarization
            plates and a second compensation plate in a portion of a
            channel matrix.

5.   Detailed description of preferred embodiments

In the following, the present invention will be described hereinafter in
more detail with reference to the accompanying figures, in which exem-
plary embodiments of the invention are illustrated. However, the present
invention may be embodied in different forms and should not be con-
strued as limited to the embodiments set forth herein. Rather, these em-
bodiments are provided so that this disclosure will be thorough and will
convey the scope of the invention to persons skilled in the art.

Fig. 1 schematically shows the essential components of a microlithographic projection exposure system 100. A light source 100 emits linearly polarized electromagnetic radiation into a beam expansion unit 120. For lithography systems in the ultraviolet (UV) or in the DUV wavelength range an excimer laser is typically applied as a light source 110. As already mentioned, KrF excimer laser systems are used for the 248 nm, ArF excimer laser systems are used for the 193 nm, and F_2 excimer laser systems are used for the 157 nm wavelength ranges. Excimer laser systems emit typically linearly polarized electromagnetic radiation. Furthermore, excimer laser systems normally emit light pulses or laser pulses having a pulse duration in the nanosecond range. It is also possible to apply the systems and methods discussed in the following to other wavelengths used in future photolithographic systems.

The beam expansion unit 120 increases the diameter of the laser beam 145 from the millimetre to the centimetre range. For example, the beam entering the expansion unit 120 can have a size of 15 nm x 20 nm and the beam exiting the expansion unit 120 may have for example dimensions of 80 mm x 80 mm.

In the exemplary embodiment of Fig. 1, the illumination system 130 comprises three different parts. The first part 131 (also called optical unit) comprises the optical components to split the light beam generated by the light source 100 and expanded by the beam expansion unit 120 in partial light beams or partial beams (not shown in Fig. 1). Details of the generation and forming of the partial beams will be discussed in the context of Fig. 2. The deflection mirror 132 directs the partial beams into the second part 134 (also called lens group). In the second part 134, the partial beams are shaped and the spatial distribution of the optical intensity is rearranged. At the exit of the second part 134, there is an intermediate field plane in which a reticle masking system (REMA) is arranged which can be used as an adjustable field stop (not indicated in Fig. 1). The third part 136 comprises the objective which images the reticle masking sys-

tem onto the wafer 150, which is arranged in a further field plane of the illumination system 130.

The projection objective 140 images the light which traversed the mask

5   150 onto a photosensitive layer 170 arranged on a substrate 160. The substrate 150 is often a silicon wafer.

Fig. 2 schematically illustrates in more detail a first portion of the illumination system 130 which is arranged in the first 131 and the second

10   134 parts of the illumination system 130. The expanded light beam 205 enters the first part 131 of the illumination system 130. A first lens 210 shapes the expanded light beam 205 for the further processing. Then, a two-dimensional raster array 215 of micro-lenses splits the expanded beam 205 in a multitude of partial beams 235. The multitude of partial

15   beams 235 is regularly arranged and mutually parallel. A further array of micro-lenses 225 adjusts the beam angles of the partial beams 235.

In an exemplary embodiment, the expanded beam has dimensions of 80 mm x 80 mm. The two-dimensional raster array of micro-lenses 215

20   splits the beam for example in squares of 4 mm x 4 mm which results in an array or in a matrix of 20 x 20 partial beams 205. This means that in the discussed example a channel 220 of a partial beam 235 has dimensions perpendicular to the beam direction of 4 mm x 4 mm. In Fig. 2, a channel 220 is symbolized by dashed lines. The two two-dimensional

25   micro-lens arrays 215 and 225 concentrate the partial beams 235 to an area of 2 mm x 2 mm. The illumination system applied at the discussion of Figures 10 – 12, which are described below, uses a multi-mirror array (MMA) of 64 x 64 mirror elements.

30   Downstream the micro-lens array 225 a polarization plate 230 is inserted in some channels 220 of partial beams 235. The polarization plate 230 changes the linear polarization of the partial beams in a defined manner for example by rotating the polarization by a predefined angle and/or by forming circularly polarized partial beams 235. Thus, the po-

larization plate 230 allows to setting up a predetermined polarization state of the beam(s) 285 exiting the illumination system 130 to illuminate the mask 150.

5   Each of the partial beams 235 strikes a respective mirror 240 of the two dimensional mirror array 250. In the discussed example, the mirrors 240 of the mirror array 250 are flat and have a size of 3 mm x 3 mm. Each of the mirrors 240 can be tilted about two tilt axes which are aligned perpendicular to each other. The tilting movement of each of the

10   mirrors 240 can be individually controlled by a control unit 260 which is connected to the mirror array 250 via the electrical connection 255.

The individual mirrors 240 are located in a square region of 4 mm x 4 mm and the square regions are located beside one another on the two-

15   dimensional mirror array 250. The number of the individual mirrors 240 is adjusted to the number of the partial beams 235 and is in the discussed example ≥ 400. The mirror array 250 is arranged on the deflection mirror 132 of the first part 131 of the illumination system 130. Instead of the mirror array 250 an array of controllable reflective diffrac-

20   tion gratings can also be used to deflect the partial beams 235 in a predetermined direction.

The optical components 265 are used to form or shape the partial beams 235 reflected from the mirrors 240. For this purpose, at least some of the

25   optical components 265 are movable along the optical axis of the illumination system 130 (not shown in Fig. 2). For example, the optical elements 265 can form a zoom-axicon objective. The exit pupil of the optical components 265 is the pupil-shaping surface of the illumination system 130.

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In the discussed example, a raster element 270 is arranged in the pupil-shaping surface or close to it. The raster element 270 has a two-dimensional array of diffractive or refractive optical elements which can fulfil several functions. The raster element 270 shapes the incident par-

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tial beams 235. Further, it forms partial beams leaving the raster element 270 which superimpose in a subsequent field plane and thus mixing the partial beams to homogeneously illuminate the exit pupil of the illumination system 130 in which the mask or reticle 150 is arranged (not indicated in Fig. 2). The raster element 270 can be realized as a two-dimensional prism array in which the individual prisms are arranged in an order to illuminate the homogenizing field plane as desired. Instead of the raster element 270, a conventional mixing element in form of an integrator rod or a fly's eye condenser can also be used (not shown in Fig. 2).

The lens 280 symbolizes the objective arranged in the third part 136 of the illumination system 130 which projects the homogenizing field plane having the mask system onto the reticle plane 290 in which the mask 150 is arranged.

The mirror array 250 changes the angular distribution of the partial beams 235 incident on the mirrors 240 of the mirror array 250, and thus rearranges the optical intensity distribution of the expanded beam 205. In the example schematically illustrated in Fig. 2, the beam 205 is concentrated into two output beams 285 which can be used to form a dipole setting. In the example of Fig. 2 the upper part of the optical beams 235 is used to form a first portion of the dipole setting, and the lower part of the optical beams 235 is used to form a second portion of the dipole setting. However, it is also possible to apply a different separation of the optical beams 235 in order to form the dipole setting of Fig. 2, or generally a predetermined setting.

Furthermore, the mirror array 250 can switch individual partial beams 235 by a respective tilting of an individual mirror in a respective portion of the pupil plane. This provides the possibility to set a desired or predetermined retardation distribution within the pupil plane of the illumination system 130 to compensate a respective retardation distribution within the pupil plane. The described retardation compensation process

has additionally to fulfil the requirement that the optical intensity is homogeneously distributed within the predetermined setting, which is a dipole setting in the example of Fig. 2.

5   On their path from the two-dimensional raster array 215 to the two-dimensional raster array 270, the partial beams 235 traverse several optical elements as for example the micro-lens array 225, the polarization plate 230, and the optical components 265. Moreover, the partial beams 235 are reflected from the mirrors 240. At each of these interactions of

10   the partial beams 235 with the optical components 215, 225, 240, 230, 265, 270, a partial beam 235 may be distorted. For example, photons of the partial beam 235 may be absorbed or scattered from the beam which results in a decrease of the intensity of the partial beam 235. Further, the phase relationship within the partial beam 235 may be distorted by the

15   interaction with the optical components 215, 225, 230, 240, 265, 270. Moreover, the polarization of the partial beam 235 may be distorted by the reflection and/or transmission of the partial beam 235 at the interfaces and/or coatings of the components 215, 225, 230, 240, 265, 270. Additionally, intrinsic or material birefringence of the optical elements

20   215, 225, 230, 265, 270 can change the polarization state of a partial beam 235.

The following description concentrates on the compensation of polarization variations which the partial beam 235 acquires during its path in the

25   respective channel 220. It is however appreciated that the discussed measures can also be used to compensate other defects of a partial beam 235.

In the next step, the fabrication of an optical element is explained which

30   is able to compensate a polarization variation of a partial beam 235. Then, examples of the insertion of the optical element in the channel 220 of a partial beam 235 are discussed.

Fig. 3 schematically depicts the effect of an intrinsic or of a material bire-
fringence of the optical components 215, 225, 230, 265, 270 of the illu-
mination system 130 of the projection exposure system 100 in the plane
290 of the mask 150. As already mentioned at the discussion of Fig. 1,
the output beam 205 of the laser source 110 is essentially linearly polar-
ized. Typically the beam 205 is horizontally polarized (in the paper plane
of Fig. 2) or vertically polarized polarized (perpendicular to the paper
plane of Fig. 2).

Fig. 3 presents an exemplary illustration of the scalar birefringence com-
ponent Ret45 which illustrates the projection of the vector retardation
onto the 45° axis, wherein the angle is measured with respect to the x-
axis. Figures 3a - 3c clearly indicate that the retardation increases
strongly toward the lens edge of the illumination system 130. Further,
Figures 3a - 3c also indicate that the retardation also strongly increases
toward the pupil edge. This means that the material birefringence of the
optical elements 215, 225, 230, 265, 270 of the illumination system 130
has both a strong field and pupil dependence.

The retardation Δ of an optical element 215, 225, 230, 265, 270, 500
having a material birefringence is determined by the thickness d of the
optical element 215, 225, 230, 265, 270, 500 and the refractive indices of
its fast n_F and slow axis n_S according to the equation:

$$\Delta = d \cdot (n_S - n_F) = d \cdot \Delta n = d \cdot \delta \qquad (1)$$

where δ is called birefringence.

The retardation Δ caused by the material birefringence of the optical
elements 215, 225, 230, 265, 270 varies the polarization state of the par-
tial beams 235, and thus results in a variation of the polarization of the
illumination beams 285 across the illumination field 290 of the mask
150. As a result, a polarization variation exemplarily dispersed in Fig. 3
by the material birefringence of the optical components 215, 225, 230,
265, 270 leads to a reduction of the intensity in preferred state (IPS).
The IPS specification is an important characteristic for the customer of

microlithographic projection exposure systems 100. Therefore, an IPS

loss has to be compensated so that the projection exposure system 100

fulfils a predetermined IPS threshold. Presently, a typical IPS specifica-

tion is for example in the range of 94 % to 98 % depending of the illumi-

5   nation setting.

This high IPS specification threshold results in a retardation budget of

the overall projection exposure system 100 including also all external

contributions in the range of approximately 10 nm. Thus, the IPS specifi-

10   cation sets new birefringence requirements to every optical element 215,

225, 230, 265, 270 of the illumination system 130 as well as for the pro-

jection system 140 of the microlithographic projection exposure system

100. Furthermore, it also makes high demands on the polarization varia-

tions induced by the mask 150, the photoresist 170 and the pellicle of the

15   mask 150 (not shown in Fig. 1). The influence of the last components

which are not part of the projection exposure system 100 is not ad-

dressed in the present invention.

Fig. 4 depicts a schematic block diagram of an apparatus 400 which can

20   be used to introduce an arrangement of local persistent modifications in

an optical element 215, 225, 230, 265, 270 and in particular to a specific

optical element 500 discussed in the context of Fig. 5 to compensate the

effect of the material birefringence of the optical elements 215, 225, 230,

265, 270 of the projection exposure system 100. The apparatus 400

25   comprises a chuck 420 which may be movable in three dimensions. An

optical element 410 may be fixed to the chuck 420 by using various tech-

niques as for example clamping. The optical element 410 may be one of

the optical elements 215, 225, 265, 270 of Fig. 2 as well as the specific

optical element 500 discussed in Fig. 5.

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The apparatus 400 includes a pulse laser source 430 which produces a

beam or a light beam 435 of pulses or laser pulses. The laser source 430

generates light pulses or laser pulses of a variable duration. The pulse

duration may be as low as 10 fs but may also be continuously increased

up to 100 ps. The pulse energy of the light pulses generated by the pulsed laser source 430 can also be adjusted across a huge range reaching from 0.01 μJ per pulse up to 10 mJ per pulse. Further, the repetition rate of the laser pulses comprises the range from 1 Hz to 100 MHz. In a preferred embodiment the light pulses may be generated by a Ti:Sapphire laser operating at a wavelength of 800 nm. However, the methods described in the following are not limited to this laser type, principally all laser types may be used having a photon energy which is smaller than the band gap to the material of the optical element 410 and which are able to generate pulses with durations in the femtosecond range. Therefore, for example Nd-YAG laser or dye laser systems may also be applied.

The apparatus 400 may also comprise more than one pulse laser sources 430 (not shown in Fig. 4).

The following table represents an overview of laser beam parameters of a frequency-doubled Nd-YAG laser system which is used in one aspect for introducing an arrangement of local persistent modifications in an optical element 410. A single local persistent modification locally modifies a density of the optical element 410. The locally modified density of the optical element 410 is discontinuously modified within at least one small volume of the optical element 410, wherein the at least one small volume is called a pixel. Furthermore, the locally modified density of a single local persistent modification induces a strain distribution around the local persistent modification of the induced pixel. By introducing or writing many pixels in a dedicated arrangement in the material of the optical element 410 a desired strain distribution can be generated.

It is known that the induced change in the impermeability $\Delta\beta_{ij}$ linearly depends on the strain induced in the material, wherein the impermeability β and the permittivity ε are linked by:

$$\varepsilon = \frac{1}{\beta}. \tag{2}$$

This dependence can be expressed with the aid of the components of the stress optic matrix:

$$\Delta\beta_{ij} = \sum_{k=1,l=1}^{3,3} q_{ijkl}\sigma_{kl} \qquad\qquad (3)$$

Therefore, the strain induced in the material of the optical element 215, 225, 230, 265, 270, 500 by introducing or writing pixels in the optical element 215, 225, 230, 265, 270, 500 is directly linked to the retardation Δ of an optical beam or the partial beam 235 in the material and is given by the equation:

$$\Delta = d \cdot n_0^3 \cdot \sqrt{\left(\frac{\beta_{11}-\beta_{22}}{2}\right)^2 + \beta_{12}^2} \qquad\qquad (4)$$

where d is again the thickness of the optical element 215, 225, 230, 265, 270, n_0 is the refractive index of the isotropic material of the optical element 215, 225, 230, 265, 270, 500 and β_{ij} are the components of the impermeability matrix of the material of the optical element 215, 225, 230, 265, 270, 500.

In the following, one set of laser beam parameters characterizing a specific laser pulse is also called a writing mode, as the laser beam is focussed into the optical element 215, 225, 230, 265, 270, 500 and laser pulses are "written" into the material of the optical element 410. Each set of laser beam or laser pulse parameters or each writing mode induces a local deformation in the optical element 215, 225, 230, 265, 270, 500 which is characteristic or specific for this parameter set. In other words, each parameter set for a laser pulse or each writing mode generates its specific deformation in the material of the optical element 410.

The effect of a laser pulse on the optical element 215, 225, 230, 265, 270, 500 is in the following described in form of a parameter called mode signature (MS). In this concept, the area of the optical element 215, 225, 230, 265, 270, 500 is divided into small elementary areas, preferably small rectangles or squares. The mode signature describes the distortion

or deformation of an elementary area due to the action of a laser pulse or a sum of laser pulses.

Table 1: Numerical values of selected laser beam parameters for a fre-
quency-doubled Nd-YAG laser system

Overview		
Parameter	Numerical value	Unit
Pulse energy	0.05 - 5	μJ
Pulse length	0.05 - 100	ps
Repetition rate	1 – 10 000	kHz
Pulse density	1 000 – 10 000 000	mm^{-2}
NA	0.1 – 0.9	
Wavelength	532	nm

The following tables indicate parameters for differently influencing the arrangement of local persistent modifications and thus the induced strain distribution in the material of the optical element 410. Table 2 presents parameters of a frequency-doubled Nd-YAG laser system for a mode of introducing or writing pixels called standard process window (Std PW).

Table 2: Numerical values of selected laser beam parameters for a Nd-
YAG laser system for a standard process window

Std PW (standard process window)		
Parameter	Numerical value	Unit
Pulse energy	0.45	μJ
Pulse length	8	ps
Repetition rate	50	kHz
Pulse density	1 000 – 100 000	mm^{-2}
NA	0.3	
Wavelength	532	nm

Table 3 summarizes parameters of a mode called low registration process window (LowReg PW) again of an embodiment using a frequency-doubled Nd-YAG laser system. This operation mode of the laser system 430 uses light pulses having a lower energy than the Std PW, but introduces a higher pixel density.

Table 3: Numerical values of selected laser beam parameters for a Nd-YAG laser system for a low registration process window (Low-Reg PW)

LowReg PW (low registration process window)		
Parameter	Numerical value	Unit
Pulse energy	0.32	µJ
Pulse length	8	ps
Repetition rate	50	kHz
Pulse density	5 000 – 500 000	mm^{-2}
NA	0.3	
Wavelength	532	nm

The steering mirror or steering system 490 directs the pulsed laser beam 435 into the focusing objective 440. The objective 440 focuses the pulsed laser beam 435 into the optical element 410. The NA (numerical aperture) of the applied objective 440 depends on the predetermined spot size of the focal point and the position of the focal point within the material of the optical element 410. As indicated in table 1, the NA of the objective 440 may be up to 0.9 which results in a focal point spot diameter of essentially 1 µm and a maximum intensity of essentially 10^{20} W/cm^2.

The apparatus 400 also includes a controller 480 and a computer system 460 which manage the translations of the two-axis positioning stage of the sample holder 420 in the plane of the x and the y direction. The controller 480 and the computer system 460 also control the translation of the objective 440 perpendicular to the plane of the chuck 420 (z direction) via the one-axis positioning stage 450 to which the objective 440 is

fixed. It should be noted that in other embodiments of the apparatus 400 the chuck 420 may be equipped with a three-axis positioning system in order to move the optical element 410 to the target location and the objective 440 may be fixed, or the chuck 420 may be fixed and the objective 440 may be moveable in three dimensions. It should be further noted that manual positioning stages can also be used for the movement of the optical element 410 to the target location of the pulsed laser beam 435 in the x, the y and the z direction and/or the objective 440 may have manual positioning stages for a movement in three dimensions.

The computer system 460 may be a microprocessor, a general purpose processor, a special purpose processor, a CPU (central processing unit), a GPU (graphic processing unit), or the like. It may be arranged in the controller 480, or may be a separate unit such as a PC (personal computer), a workstation, a mainframe, etc. The computer system 460 may further comprise I/O (input/output) units like a keyboard, a touchpad, a mouse, a video/graphic display, a printer, etc. In addition, the computer 460 may also comprise a volatile and/or a non-volatile memory. The computer system 460 may be realized in hardware, software, firmware, or any combination thereof. Moreover, the computer system 460 may control the laser source 430 (not indicated in Fig. 4).

Further, the apparatus 400 may also provide a viewing system including a CCD (charge-coupled device) camera 465 which receives light from an illumination source arranged to the chuck 420 via the dichroic mirror 445. The viewing system facilitates navigation of the optical element 410 with respect to the target position. Further, the viewing system may also be used to observe the formation of the pixel arrangement in the optical element 410 by the pulse laser beam 435 of the light source 430.

Fig. 5 schematically represents an optical element 500 which is prepared to compensate a polarization variation of a partial beam 235 in a channel 220. The optical element 500 comprises an optically relevant area 510 which the partial beam 235 traverses. The optical element 500 can be of

any material which is transparent for the respective wavelength of the partial beam 235. In the DUV range quartz or calcium difluoride (CaF_2) can for example be applied to fabricate the optical element 500. In order to introduce a significant amount of retardation, the material of the opti-

5   cal element 500 should be amorphous; especially amorphous quartz is applicable.

In the example discussed in the context of Fig. 2, the optically relevant area 510 of the optical element 500 has a size > 2 mm x 2 mm. The opti-

10   cally relevant area 510 is surrounded by an optically not relevant area 520. In the discussed example, the outer dimensions of the optically not relevant area 520 are ≤ 4 mm x 4 mm. A mounting is attached to the optically not relevant area 520 in order to insert and to fix the optical element 500 in the channel 220 (not shown in Fig. 5).

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The optically not relevant area 520 is used to introduce one or several arrangements 530, 540 of local persistent modifications. The arrange-ments 530, 540 are indicated in Fig. 5 to just illustrate the principle. At the explanation of the apparatus 400, i.e. during the discussion of Fig. 4,

20   it is described in detail how the introduction of an arrangement of local persistent modifications or pixels introduces a defined local strain dis-tribution which causes a defined strain induced birefringence. In the example of Fig. 5, the pixel arrangements 530, 540 result in a birefrin-gence where the fast axis is oriented along the corners having the pixel

25   arrangements 530, 540 and the amount of retardations is essentially zero at the centre and increases toward the corners having the pixel ar-rangements 530, 540.

Fig. 2 reveals that the material birefringence of the optical components

30   215, 225, 230, 265, 270 results in a systematic dependence of the retar-dation in the pupil plane. It is therefore a first approach to compensate the material birefringence of the optical components 215, 225, 230, 265, 270 by fabricating optical elements 500 which have a fixed fast axis and various maximum amounts of retardations. As indicated by equation (1)

this can be performed by either varying the thickness of the optical element 500 or by varying the strain induced birefringence by changing the pixel arrangements 530, 540. It is also possible to use a combination of a variation of both parameters in order to fabricate an optical element 500

5   having a predetermined amount of retardation. The various optical elements 500 can then be inserted in the channels 220 of the respective partial beams 235 to compensate the respective polarization variation in the pupil plane.

10   This approach has the advantage that the polarization variation of the optical elements 215, 225, 230, 265, 270 of individual channels 220 has not to be analysed. Further, it is not necessary to determine individual pixel arrangements 50, 540 for each of the optical elements 500. Therefore, this approach is discussed in the following examples.

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         However, it has to be stressed that it is in a second approach also possible to measure the polarization variation of the optical components 215, 225, 230, 265, 270 of an individual channel 220 and calculate from this data a respective pixel arrangement 530, 540 for an individualized defect

20   compensation of the optical element 500.

         Furthermore, the optical element 500 can also be equipped with one or more actuators to temporarily induce a strain induced birefringence (not shown in Fig. 5). This allows a dynamic setting of the retardation during

25   the operation of the illumination system 130. The actuator can be arranged to modify the fast axis of the birefringence of the optical element 500, and thus modify both the orientation of the fast axis and the retardation. On the other hand, it can be arranged to just vary the retardation but leaving the orientation of the fast axis unchanged. For example a piezo-

30   element can be applied as an actuator.

         Furthermore, the optical element 500 may be dynamically inserted in the channel 220 depending on the adjustments of the optical components in the channel 220, in particular as a consequence of a movement

of the optical elements 265. This enables a flexible response to various settings of the illumination system 130.

Fig. 6 shows a cut-out of Fig. 2. The raster element 215 of Fig. 2 gener-

5   ates four incident partial beams 605, 610, 615, 620 which are linearly polarized having their polarization horizontally oriented in the sheet plane. After traversing the focussing micro-lens array 640, polarization plates 652, 654, 656 are inserted in the partial beams 610, 615, 620 in order to change the polarization of the incident partial beams 610-620

10   by a predetermined amount. As can be seen from Fig. 6, each polariza- tion plate 650 rotates in this example the polarization of the beams 610, 615, 620 by 45° ($\pi/4$). As the action of the polarization plates 652, 654, 656 are additive, the partial beam 615 is rotated by 90° and the partial beam 620 is rotated by 135° with respect to the polarization of the partial

15   beam 670. The mirrors 660 reflect the partial beams 605-620 in a prede- termined direction as is indicated in Fig. 2.

In order to generate a predetermined polarization when superimposing the partial beams 605-620, it may however be required that the partial

20   beam 620 has an elliptically polarization instead of a linear polarization. For this purpose, an optical element 500 is inserted in the channel of the partial beam 620 having one or several arrangements 530, 540 of local persistent modifications which generate a strain induced birefringence with a fixed fast axis and a defined retardation in order to generate in

25   combination with the polarization plate 656 the required polarization of the partial beam 785.

Fig. 7 illustrates this situation. An optical element 500 having a prede- termined retardation is inserted in the partial beam 620 and changes the

30   polarization of the reflected beam 785 according to the retardation of the optical element. As the incident beam 620 is linearly polarized the effect of the optical element 500 depends on the orientation of its fast axis relative to the polarization of the partial beam 620. An angle of ±45° between the fast axis of the optical element 500 and the polarization of

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the partial beam 620 has a maximum effect on the polarization. The sign of the fast axis of the optical element 500 has to be different to the sign of the effective retardation axis of the illumination system in order to result in a compensation of the polarization variation.

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The insertion of the optical element 500 upstream of the polarization plates 650 is beneficial as this arrangement facilitates the orientation of the fast axis of the optical element 500 with respect to the polarization of the partial beam 620. On the other hand, it is also possible to arrange the optical element 500 downstream of the polarization plates 652, 654, 656 when the orientation of its fast axis of the optical element 500 is controlled with respect to the polarization of the partial beam 620.

The impact of the optical element 500 is controlled by the IPS variation of the respective illumination beam 285.

Fig. 8 shows that an optical element 500 inserted in a channel 220 having a defect in particular a polarization defect can also be used to compensate a polarization defect in a second channel when the partial beams 235 are superimposed in a single spot. Fig. 8 depicts two partial beams 235 whose polarizations are described by Stokes vectors S_1 and S_2. Both partial beams 235 pass through an optical element 500 introducing various amounts of retardations indicated as Ret_1 and Ret_2. Furthermore, the second partial beam 235 traverses one of the polarization plates 652, 654 or 656, so that that the partial beams 235 have different polarization rotations φ_1 and φ_2. Therefore, the Stokes vectors of the two partial beams are:

$$S_1 = \begin{pmatrix} 1 \\ \cos(2\varphi_1) \\ -\sin(2\varphi_1) \\ \mathrm{Re}\,t_1 \end{pmatrix}, S_2 = \begin{pmatrix} 1 \\ \cos(2\varphi_2) \\ -\sin(2\varphi_2) \\ \mathrm{Re}\,t_2 \end{pmatrix} \tag{5}$$

If the two partial beams 235 are superimposed by a respective tilting of the mirrors 240 or 660, the polarization of the superimposed beam is described by the Stokes vector S_{sum}:

$$S_{sum} = S_1 + S_2 = \begin{pmatrix} 2 \\ \cos(2\varphi_1) + \cos(2\varphi_2) \\ -\sin(2\varphi_1) - \sin(2\varphi_2) \\ \mathrm{Re}\, t_1 + \mathrm{Re}\, t_2 \end{pmatrix} \qquad (6)$$

This demonstrates that the retardation introduced by the optical element 500 is also effective when an additional polarization rotation is generated by the polarization plates 650. This means that an optical element 500 inserted in a channel 220 of a partial beam 235 can also compensate polarization defects in various other channels at the superposition of the partial beams 235 even if the other channels have different polarization states due to the action of the polarization plates 652, 654, 656.

It can be useful to prepare a set or polarization plates 652, 654, 656 having a different amount of strain induced birefringence. Furthermore, it is also conceivable to introduce a pixel arrangement 530, 540 in one or more of the optical components 215, 225, 265, 270. In specific situations, a combination of an optical element 500 and a further compensation measure by the introduction of one or more pixel arrangements 530, 540 in one of the optical components 215, 225, 230, 265, 270 can also be used.

Moreover, there may be configurations of the illumination system 130 in which it is more effective to use a plate or a compensation plate acting on more than just one channel 220 instead of the optical element 500. It may be useful to apply a compensation plate for a portion of the channel matrix. For example, a compensation plate may be fabricated for a quarter of the two-dimensional channel matrix for the partial beams 235. Such a compensation plate may for example beneficially be used for a quadrupole setting of the illumination system 130.

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Fig. 9 presents a 4 x 4 compensation plate 900 for a channel-wise com-
pensation of a birefringence, in particular a material birefringence of the
optical components 215, 225, 230, 265, 270 in the channel 220 of the
partial beams 235. As already mentioned above, the multi-mirror array
(MMA) 130, 660 of the illumination system 130 considered in Figures 9
to 12 comprises an arrangement of 64 x 64 mirrors. The compensation
plate 900 comprises channels 220, as for example the channels 220 of
the third column, which do not act on the polarization of the respective
partial beams 235. Furthermore, it has optically relevant areas 910 which
provide a strain induced birefringence of different orientations of the
fast axis and various amounts of retardations.

In the example of Fig. 9, the arrangements of local persistent modifica-
tions are introduced or written outside of the optically relevant area.
This area is named in Fig. 9 as area of structuring. Fig. 9 just indicates
that it is possible to fabricate a compensation plate 900 having various
orientations of the fast axis and also having different amounts of retarda-
tions on a single compensation plate 900.

Fig. 10 illustrates various configurations for a 4 x 4 compensation plate.
Fig. 10a shows a plate in which the optical areas of the second row have
birefringence distributions with a different orientation of the fast axis
and various amounts of retardations. Fig. 10b indicates the configuration
of Fig. 10a, wherein the strain induced birefringence of the second row of
Fig. 10a is repeated in the fourth row of Fig. 10b. Fig. 10c presents a con-
figuration in which the orientation of the fast axis is fixed in one row but
having different amounts of retardations. Finally, Fig. 10d distributes the
strain induced birefringence to all rows of the compensation plate. For
each of the polarization plates 652, 654, 656 there are channels which
have a retardation effect and other ones which do not have it. In the case
of a static approach, it is therefore possible to optimally set the compen-
sation effect by means of a Pol-CompPup algorithm which calculates the
mirror tilting angles of the mirrors 240 in order to optimize the illumi-

nation pupil. It simultaneously optimizes the desired intensity distribution, the desired (linear) polarization distributions and the required retardation distribution by setting each of the mirrors 240, the three polarization plates 652, 654, 656 and of the compensation plate 500.

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As already mentioned at the discussion of the optical element 500, if the compensation plate 900 is inserted upstream of the polarization plates 652, 654, 656, the compensation plate 900 needs only to have two orientations of the fast axis which are ±45° relative to the polarization of the
10   partial beams 235, 605-620. The following figures indicate a few conceivable implementation possibilities of a compensation plate 900 in combination with the polarization plates 652, 654, 656.

Fig. 11 shows an example in which a compensation plate having twice the
15   configuration of Fig. 10b is used in combination with three polarization plates (PolFlex plate 1 to PolFlex plate 3) for a partial channel matrix. In this configuration, there are channels 220 for each polarization state which correct the birefringence of the respective channel, i.e. channels 220 having a fast axis of +45° and -45° as well as retardations of 3 nm
20   and 5 nm for each fast axis orientations. There are also some channels 220 which do not have any effect on the polarization of the respective polarization state. Consequently, the retardation of the partial beams 235 forming an exiting beam generated from a superposition of the partial beams 235 of this portion of the channel matrix can very largely be
25   compensated.

Fig. 12 again presents an example with three polarization plates (PolFlex plate1 to PolFlex plate 3) and a compensation plate. In contrast to the example of Fig. 11, the compensation plate having once the configuration
30   of Fig. 10a is used to compensate the retardation effect of various channels of the presented channel matrix cut-out. In order to optimize the compensation of the polarization variation of the channels 220 of the partial channel matrix, the compensation plate is dynamically moved

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within the channel matrix cut-out of Fig. 12. The movement of the compensation plate is independent from the polarization plates.

Claims

1. An illumination system of a microlithographic projection exposure apparatus comprising:

   a. a plurality of channels, each channel guiding a partial beam and at least one channel comprising at least one defect; and

   b. at least one optical element arranged within the at least one channel having the at least one defect, the optical element being adapted to at least partially compensate the at least one defect of the partial beam of the channel.

2. The illumination system of claim 1, wherein the at least one defect comprises a variation of the polarization of the partial beam in the at least one channel.

3. The illumination system of claim 1 or 2, wherein the at least one optical element at least partially compensates the at least one defect by modifying a polarization of the partial beam.

4. The illumination system of any of the preceding claims, wherein the at least one optical element comprises a strain induced birefringence which at least partially compensates the variation of the polarization of the partial beam.

5. The illumination system of claim 4, wherein the strain induced birefringence comprises introducing at least one arrangement of local persistent modifications in an area of the optical element outside of its optically relevant area.

6.   The illumination system of any one of the preceding claims, wherein a mirror of a two dimensional mirror array directs a partial beam passing through the at least one optical element in an outer edge of a pupil in agreement with a predetermined target pupil.

7.   The illumination system of any one of the preceding claims, wherein the strain induced birefringence of the at least one optical element comprises a fast axis having a fixed direction.

8.   The illumination system of any one of the preceding claims, wherein the strain induced birefringence of the at least one optical element comprises a retardation in the optical relevant area of the at least one optical element of 1 nm - 10 nm, preferably 2 nm - 8 nm, and most preferably 3 nm - 6 nm.

9.   The illumination system of claims 7 or 8, wherein the at least one optical element maximizes a modification of the polarization of the partial beam by selecting an orientation of the fast axis of the at least one optical element with respect to a polarisation of the partial beam in the channel.

10.   The illumination system of any one of the preceding claims, wherein the illumination system is adapted to superimpose partial beams of at least one first channel and at least one second channel in a single spot, so that a retardation of the superimposed beams compensates the retardation of the illumination system.

11.   The illumination system of claim 10, wherein the polarization of the partial beam of the at least one first channel is rotated by a predetermined amount with respect to the polarization of the partial beam of the at least one second channel.

12.   The illumination system of any one of the preceding claims,
        wherein a compensation of the at least one defect increases an in-
        tensity in preferred state of a beam exiting the illumination sys-
        tem.

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13.   The illumination system of any one of the preceding claims,
        wherein the at least one optical element is adapted to comprise
        an actuator to induce strain in the optically relevant area of the at
        least one optical element.

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14.   The illumination system of any one of the preceding claims,
        wherein the at least one optical element is adapted to be dynami-
        cally inserted in the at least one channel during an operation of
        the illumination system.

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15.   The illumination system of any one of the preceding claims,
        wherein the at least one optical element comprises a multitude of
        optical elements being fabricated with different fixed fast axes
        and/or different amounts of retardations.

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16.   The illumination system of claim 15, wherein the multitude of
        optical elements is adapted to be inserted in a multitude of chan-
        nels each one having a defect so that the intensity in preferred
        state of the beam exiting the illumination system is maximized.

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17.   The illumination system of any one of the preceding claims,
        wherein the at least one optical element is adapted to comprise a
        polarizer which changes the polarization of the partial beam by a
        predetermined amount.

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18.   The illumination system of claims 1 - 16, wherein the at least one
        optical element comprises a mirror for reflecting the partial
        beam.

19. The illumination system of claims 1 - 16, wherein the at least one optical element comprises a lens for deflecting the partial beam.

20. The illumination system of any one of the preceding claims, wherein the at least one optical element is adapted to comprise at least one plate having at least two optically relevant areas for at least two channels, the optically relevant areas are arranged between areas of the at least one plate which are optically not relevant.

21. The illumination system of claim 20, wherein the at least two optically relevant areas are arranged in a one-dimensional row or a two-dimensional rectangular matrix, the at least two optically relevant areas have a diameter which is adjusted to a diameter of the partial beams, and the at least two optically relevant areas have a distance which is adjusted to a distance between the partial beams of the at least two different channels.

22. The illumination system of claim 20 or 21, wherein the plate comprises at least two optically relevant areas being adapted to compensate at least two different defects.

23. The illumination system of claims 20 - 22, wherein the at least two optically relevant areas of the plate comprise a polarizer which change the polarization of the partial beam by a predetermined amount.

24. The illumination system of claim 5, wherein ultra-short laser pulses are used to introduce the at least one arrangement of local persistent modifications.

25. The illumination system of claims 20 - 23, wherein the plate is adapted to be moved and/or to be rotated essentially perpendicular to the beam directions of the at least two partial beams.

26.   The illumination system of claims 20 – 23 or 25, wherein the
        plate is adapted to be dynamically inserted in a beam path of the
        partial beams of the least two channels during the operation of
        the illumination system.

27.   A method for compensating at least one defect in at least one
        channel of an illumination system of a microlithographic projec-
        tion exposure system, the method using an illumination system
        of any of the claims 1 - 26.

28.   The method of claim 27, further comprising the step of inserting
        at least one optical element in at least one channel having a de-
        fect which is best compensated by the at least one optical ele-
        ment.

Figures
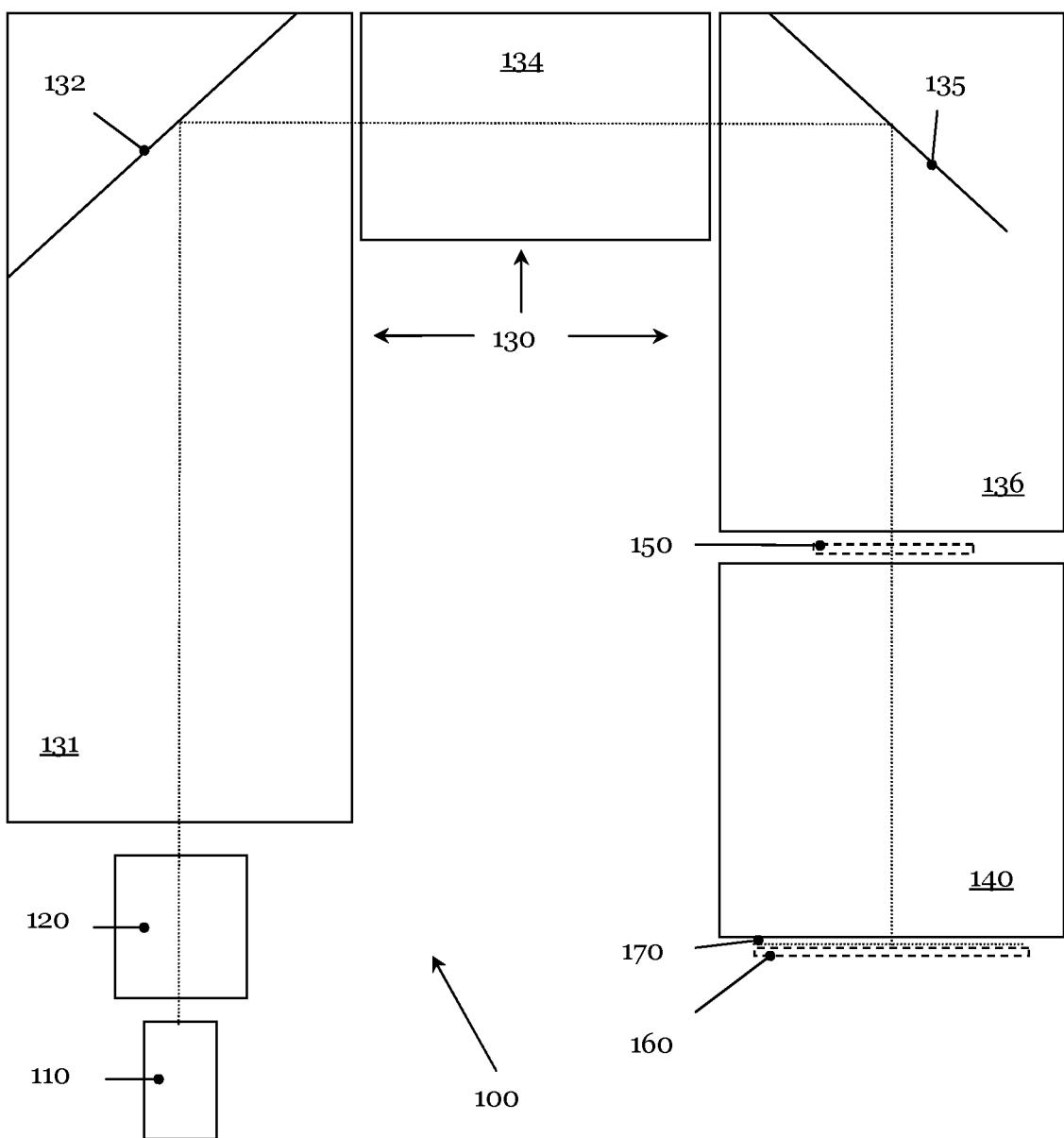
Fig. 1

Fig. 2
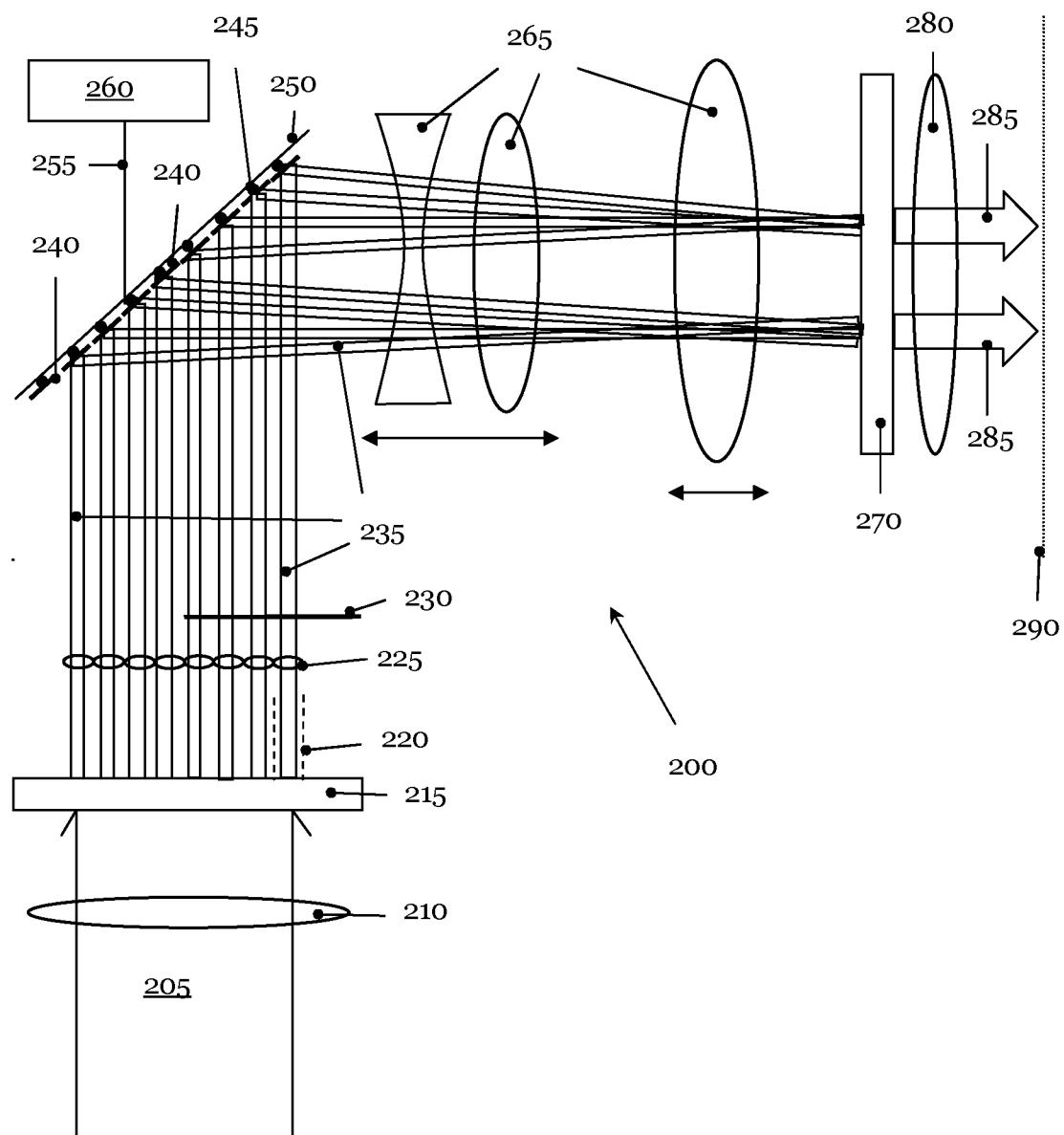
**Fig. 3a**
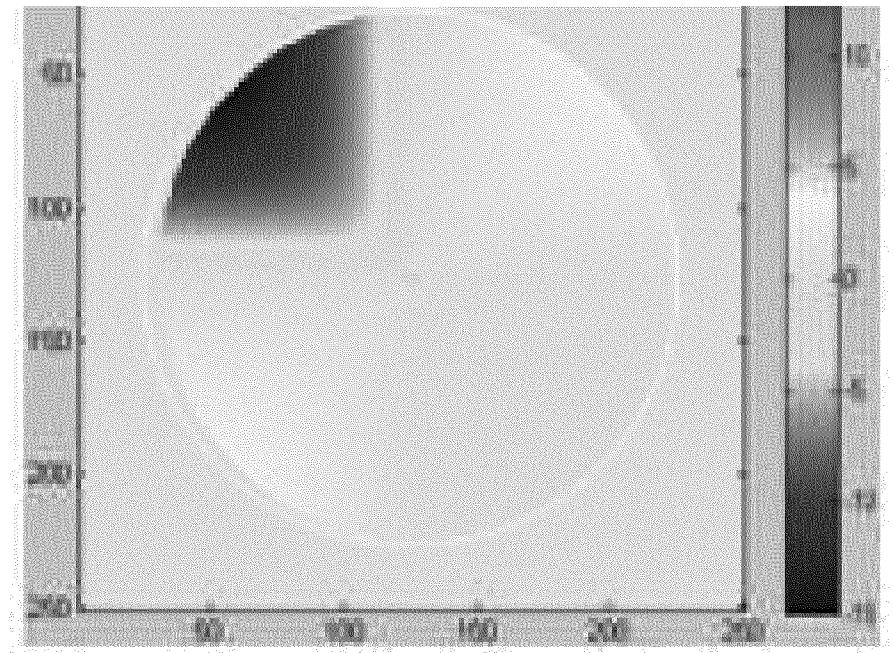
Fig. 3b

Fig. 3c

Fig. 4

Fig. 5

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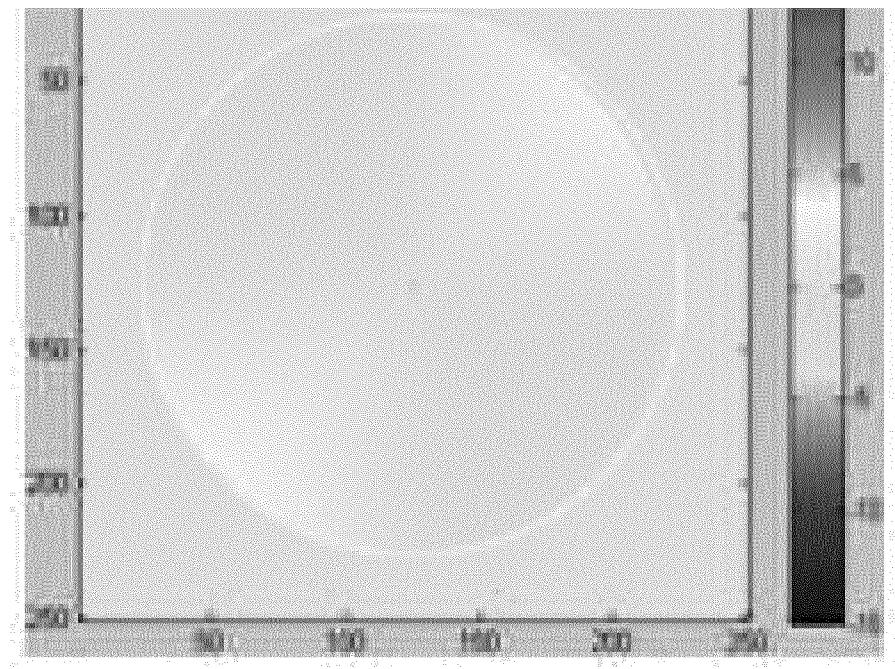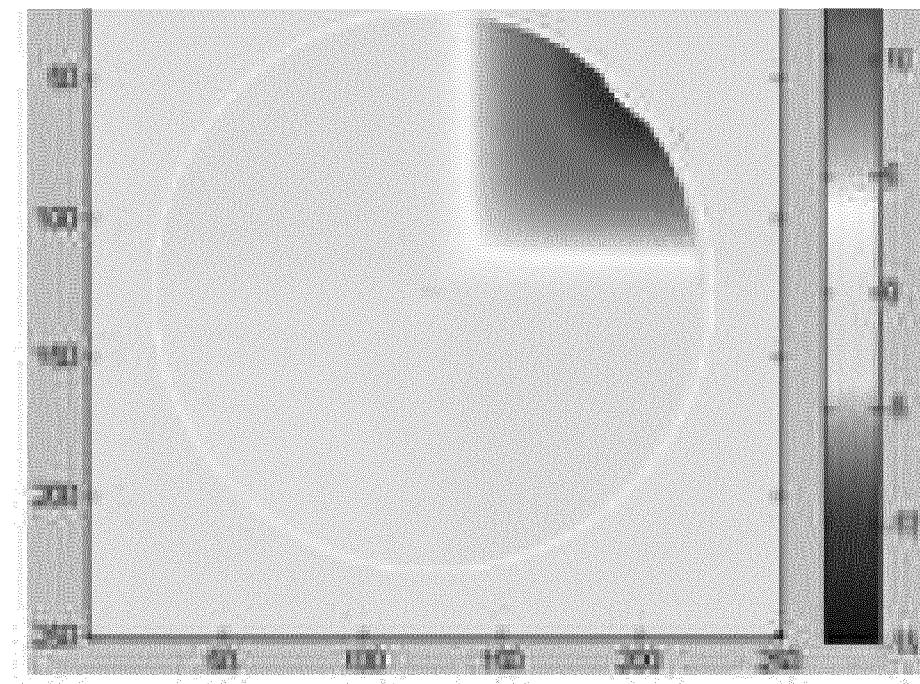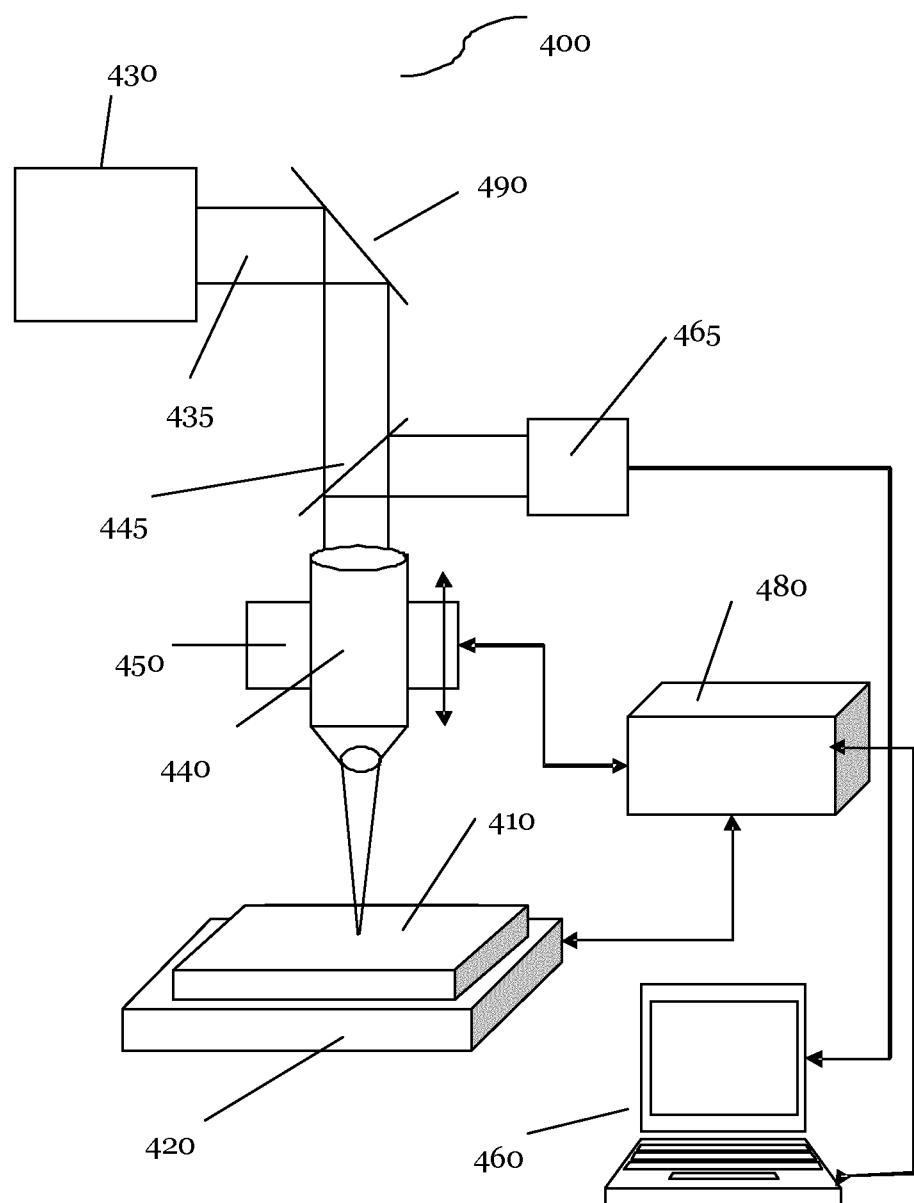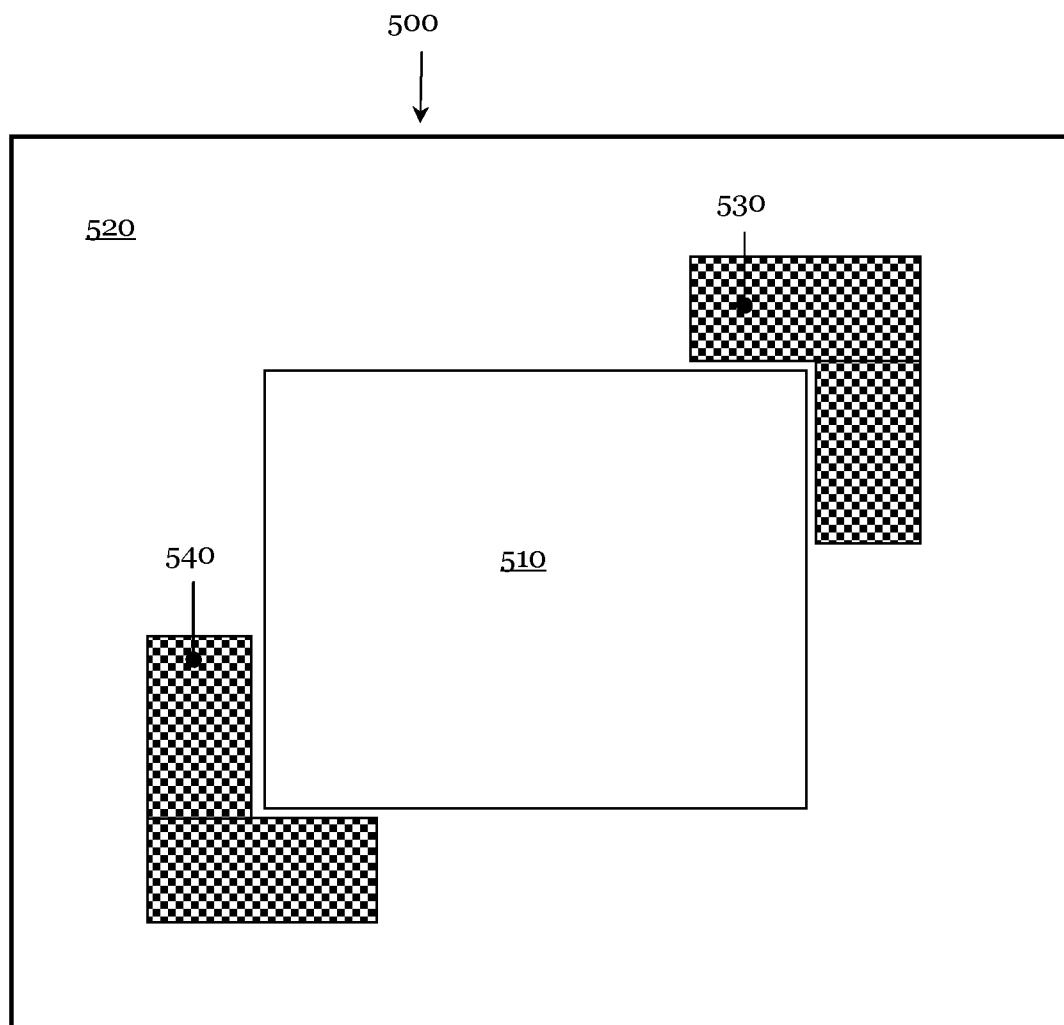
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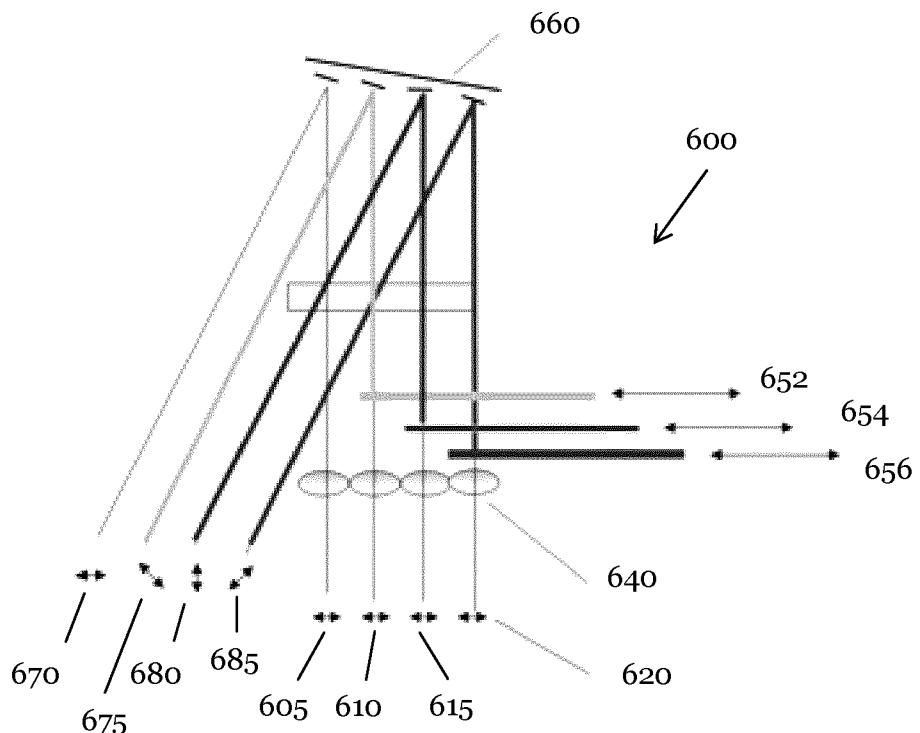
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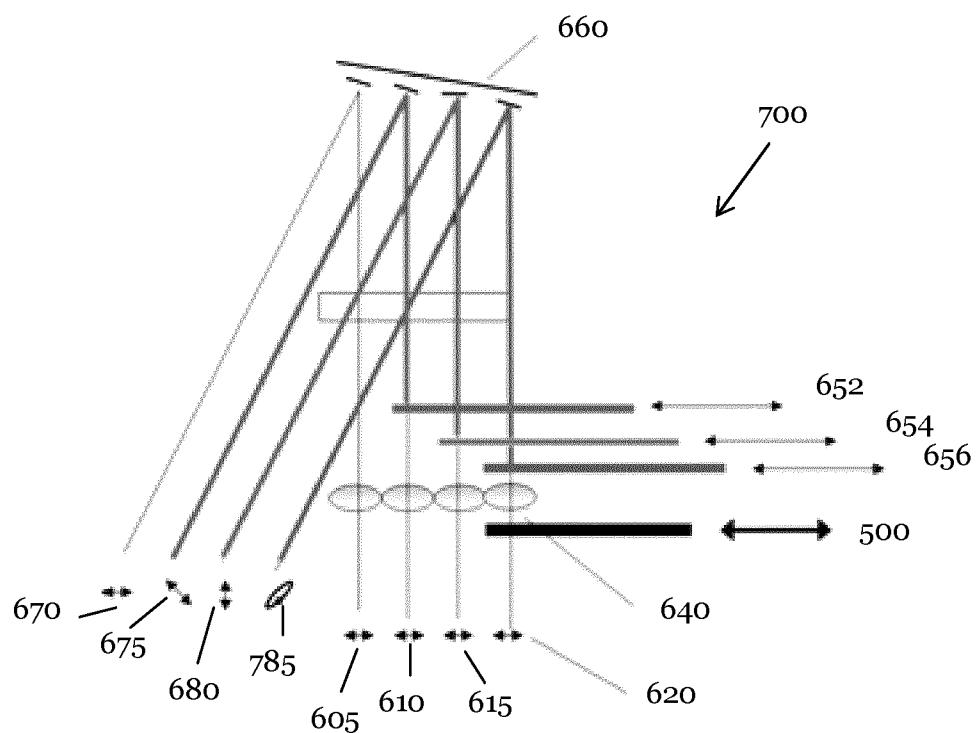
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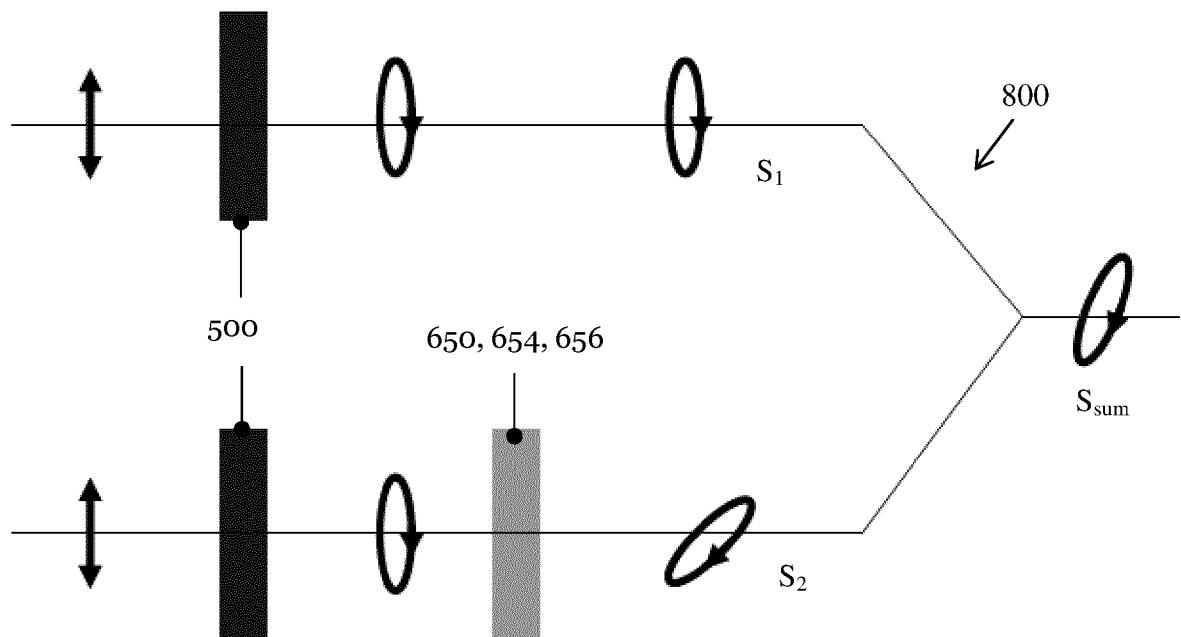
Fig. 9
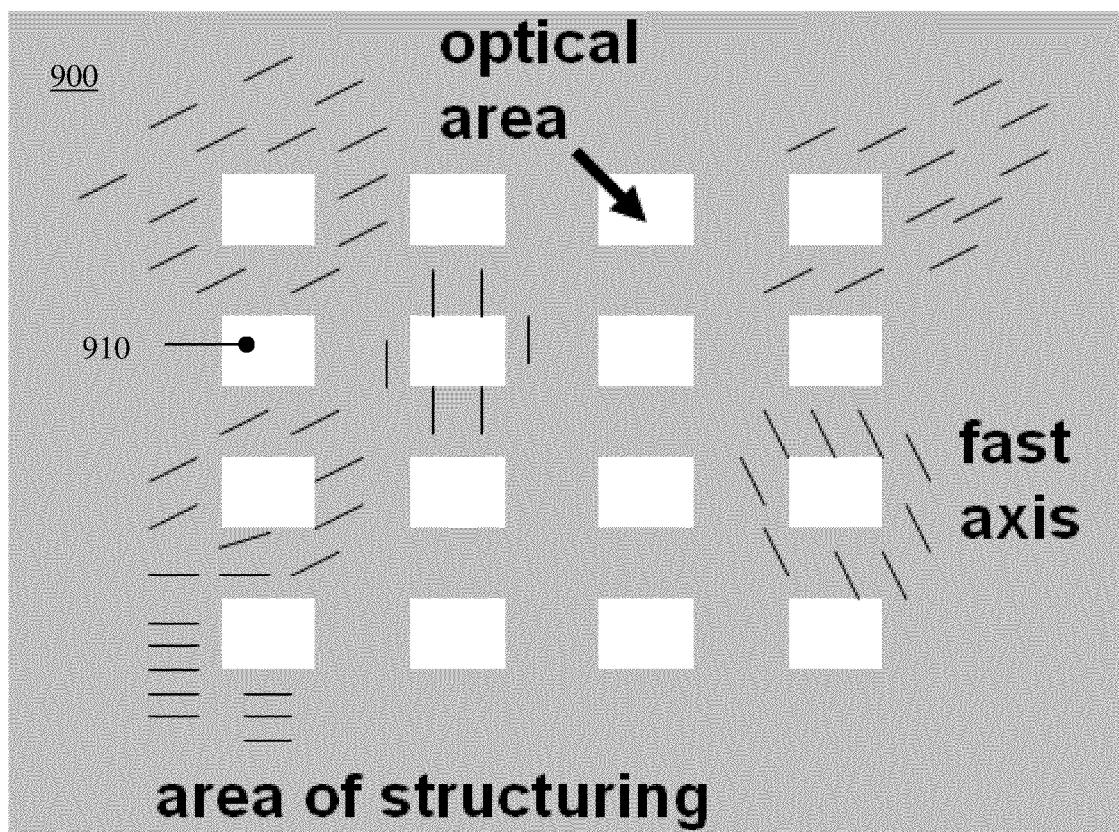
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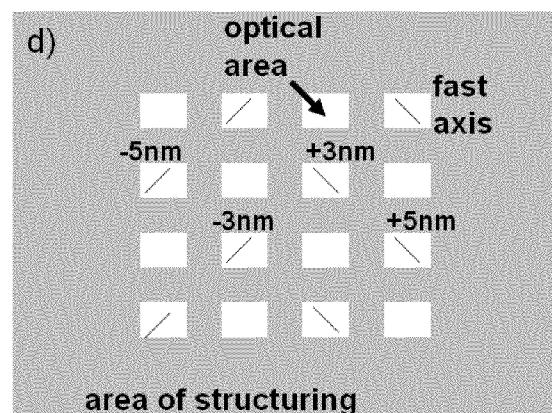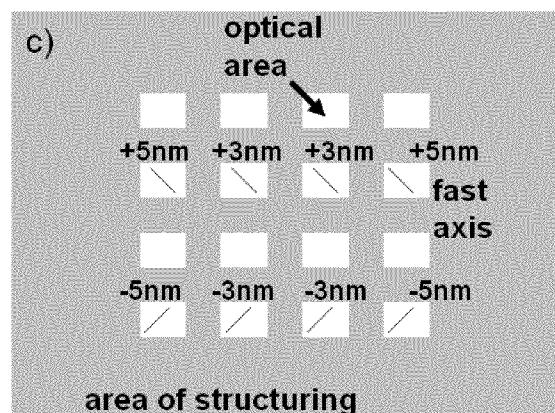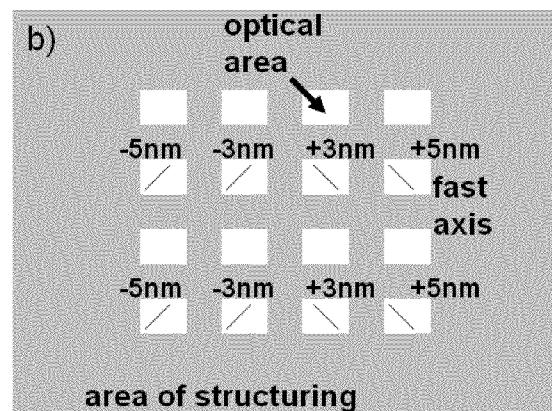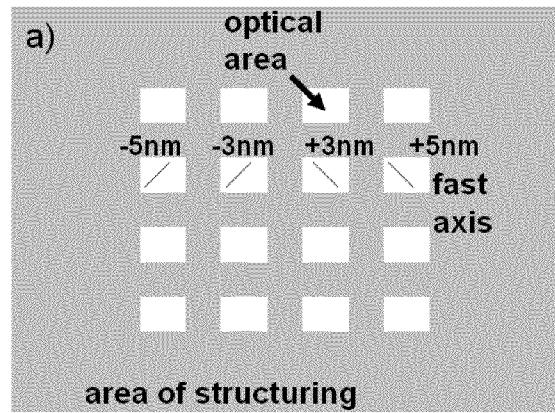
Fig. 11
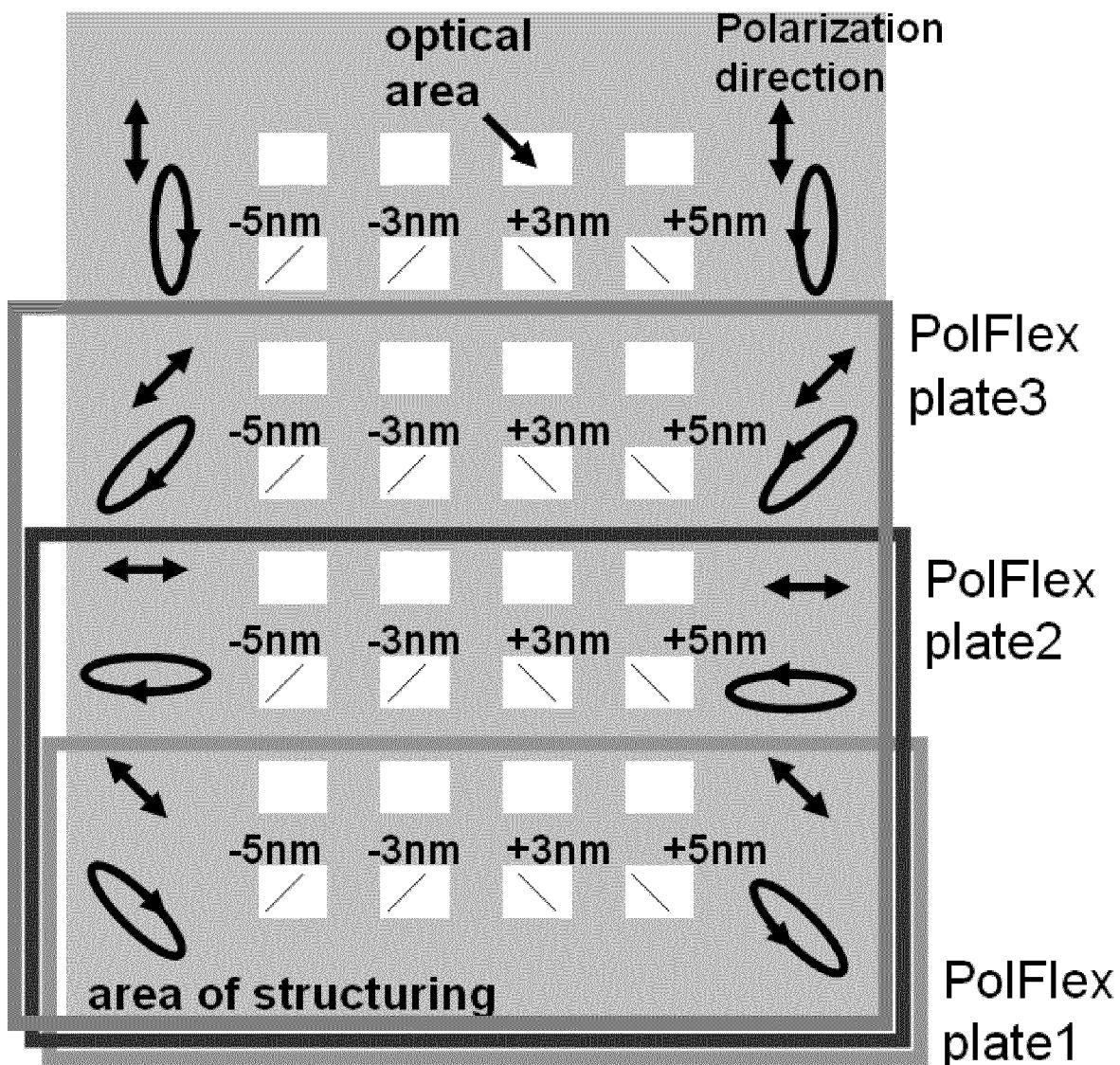
Fig. 12
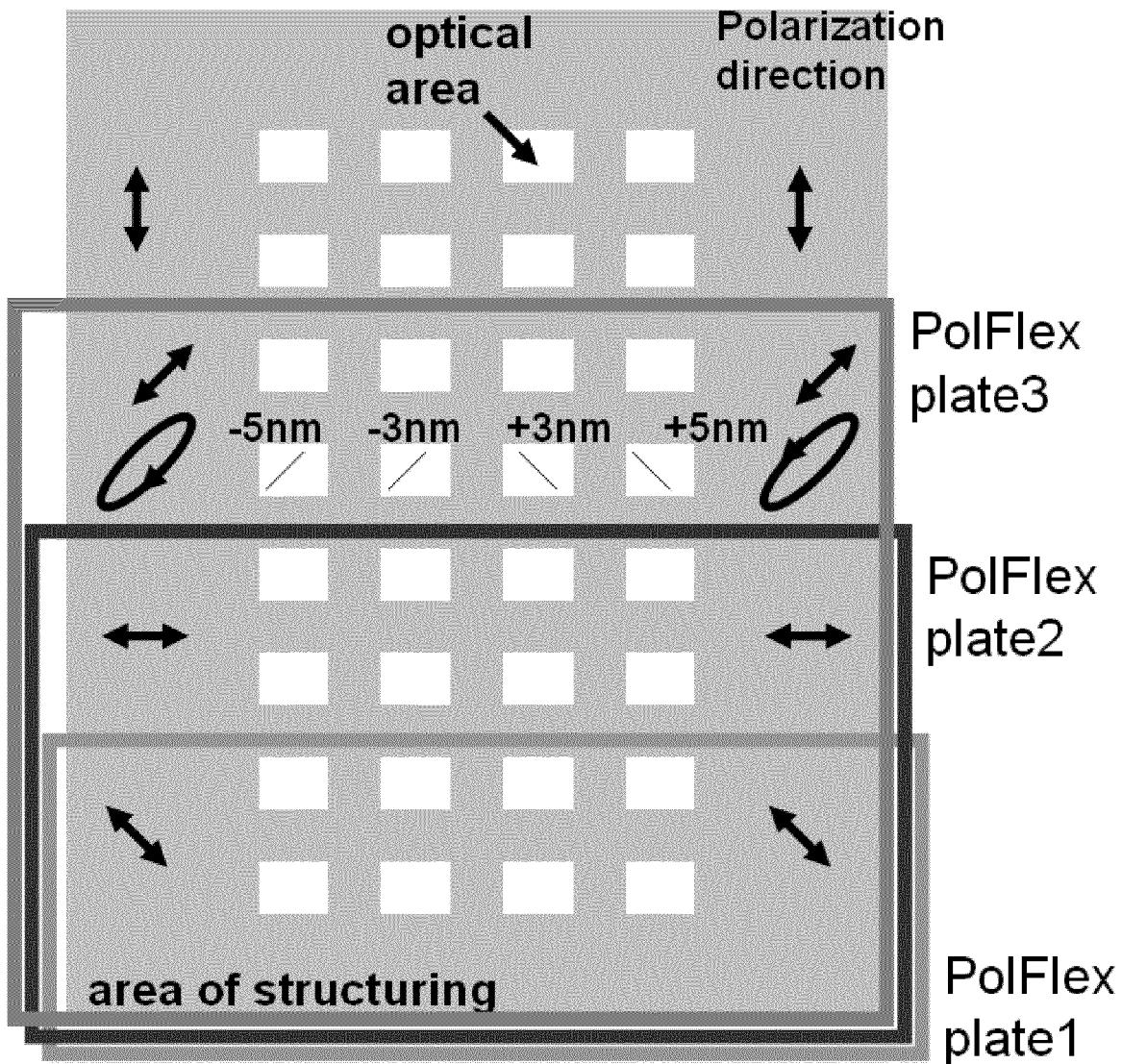
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. G03F7/20
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G03F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/058274 A1 (SINGER WOLFGANG [DE] ET AL) 15 March 2007 (2007-03-15) paragraphs [0024], [0083] - [0088], [0101] - [0105]; figures 6, 12 -----	1,6,18, 19,27,28
Y	EP 2 369 413 A2 (ASML NETHERLANDS BV [NL]; ZEISS CARL SMT AG [DE]) 28 September 2011 (2011-09-28) paragraphs [0034] - [0037], [0045] - [0051]; figures 2, 4a-4c -----	1-4,7-9, 12-17, 20-23, 25-28
Y	US 2005/146704 A1 (GRUNER TORALF [DE] ET AL) 7 July 2005 (2005-07-07) paragraphs [0074], [0075], [0106] - [0110]; figures 3, 9 -----	1-4,7-9, 12-17, 20-23, 25-28

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Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2012	08/01/2013

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

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Information on patent family members

Patent document cited in search report			Publication date	Patent family member(s)			Publication date
US 2007058274	A1		15-03-2007	AT	502323	T	15-04-2011
				EP	1649324	A2	26-04-2006
				JP	5026788	B2	19-09-2012
				JP	2007500432	A	11-01-2007
				KR	20060039876	A	09-05-2006
				US	2007058274	A1	15-03-2007
				WO	2005015314	A2	17-02-2005
EP 2369413	A2		28-09-2011	CN	102200693	A	28-09-2011
				EP	2369413	A2	28-09-2011
				JP	2011199285	A	06-10-2011
				KR	20110106246	A	28-09-2011
				SG	174692	A1	28-10-2011
				TW	201211700	A	16-03-2012
				US	2011228247	A1	22-09-2011
US 2005146704	A1		07-07-2005	US	2005146704	A1	07-07-2005
				US	2009040496	A1	12-02-2009
				US	2011069296	A1	24-03-2011