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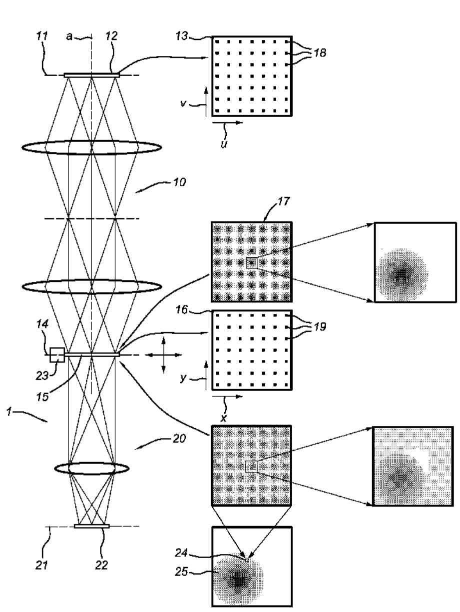
(54) **Title:** OPTICAL DEVICE AND METHOD FOR MEASURING SPATIALLY-VARYING ABERRATIONS OF AN IMAGING SYSTEM

Fig. 1



(57) Abstract: Optical device (1) for measuring spatially-varying aberrations of an imaging system (10); the imaging system configured for scaled projecting along an optical axis of a periodic object pattern (13) arranged in an object plane (11) of the imaging system; the optical device comprising an object mask (12), an image mask (15) and an image detector; the object mask (12) positioned at the object plane (11) and provided with the object pattern (13); the image mask (15) positioned at the image plane (14) and provided with an image pattern (16) of which the pitches corresponding to the scaled object pattern; the image detector comprising projection optics (20) and a sensor array (22), wherein the sensor array and the projection optics are arranged for projecting the image pattern along the optical axis on the sensor array, and are configured to project each sub-region of the image pattern on an associated pixel cluster (24) in the sensor array (22).

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Optical device and method for measuring spatially-varying aberrations of an imaging system

Technical field

The invention relates to an optical device and method for measuring spatially-varying aberrations of an imaging system.

Background art

Digital semiconductor devices are usually made by (photo)lithography systems, which transfer a geometrical pattern from a mask to a light sensitive photoresist on a wafer. The transfer of the pattern is done using an imaging system, projecting the pattern on the wafer. The quality and sharpness of the pattern on the wafer thus heavily relies on the quality of the imaging system. In particular, any spatially-varying aberration in the imaging system deteriorates the quality of the pattern. These aberrations cause a different performance at different locations in the field-of-view (FOV) of the imaging system.

The imaging system comprises a plurality of optical elements comprising lenses, mirrors or a combination of both. During fabrication of the imaging system, a shift or tilt of any optical element may result in imperfections in the projected pattern. Also, while making the semiconductor devices, any heat, vibration and contamination may cause imperfections in the imaging system too. Spatially-varying aberrations are widely present in imaging systems e.g. for lithography.

Examples of spatially-varying aberrations are tangential astigmatisms, sagittal astigmatism, curvature of the field, barrel distortion, pincushion distortion, and coma. Generally, the spatially-varying aberrations can be described in terms of the coordinates of the pupil of the imaging system (u,v) and the coordinates of the FOV (x,y) by a four-dimensional function $\Phi(u,v;x,y)$.

Aberration measurements can be done either directly or indirectly. Direct methods include wave front sensing and interferometry. Indirect methods retrieve the aberrations from the measured distorted or blurred images. In the indirect methods, the spatially-varying aberrations are often characterised by means of Moiré patterns, such as for example described in US 7,019,824. However, methods using Moiré patterns are only sensitive to distortion and a limited number of other characteristics.

It is an object of the invention to provide an optical device and indirect method for measuring spatially-varying aberrations of an imaging system which is more efficient and not limited to specific types of aberrations, and/or at least reduces some of the disadvantages of the prior art.

Summary of the invention

According to an aspect of the invention, there is provided an optical device for measuring spatially-varying aberrations of an imaging system;

the imaging system configured for scaled projecting along an optical axis of an object pattern arranged in an object plane of the imaging system as a scaled image thereof on an image plane of the imaging system;

the optical device comprising an object mask, an image mask and an image detector;

the object mask positioned at the object plane and provided with the object pattern, wherein the object pattern is a periodic array with features arranged with a first pitch in a first pitch direction and a second pitch in a second pitch direction, preferably orthogonal to the first pitch direction;

wherein the features are adapted to change an amplitude and/or a phase of incident radiation; and wherein the periodic array is divided into sub-regions which each include at least one feature;

the image mask positioned at the image plane and provided with an image pattern with a first pitch and second pitch, wherein the first pitch and second pitch of the image pattern correspond to the first pitch and second pitch of the object pattern scaled in accordance with a scaling ratio of the imaging system;

the image detector comprising projection optics and a sensor array, wherein the sensor array is a pixelated sensor array at a fixed position relative to the object mask and the projection optics are arranged for projecting the image pattern along the optical axis on the sensor array, and are configured to project each sub-region of the image pattern on an associated pixel cluster in the sensor array;

and the optical device is adapted to translate the image mask and/or the object mask in a direction perpendicular to the optical axis.

Using this optical device, the image of the object pattern in each sub-region of the FOV can be obtained simultaneously by the associated pixel cluster via scanning the image mask and/or the object mask, preferably as a function of predefined scanning positions. Preferably, the image mask is scanned in two orthogonal directions and preferably over a distance of one pitch in each direction. In one complete scanning, the optical device can simultaneously measure images of the object pattern in a number of sub-regions that equals the number of the pixel clusters in the sensor array.

Local aberrations can be retrieved from the measurement of the image in the associated sub-region. The local aberrations at each sub-region form a two-dimensional function. Combining all local aberration functions from all sub-regions thus gives the high-resolution measurement of the four-dimensional spatially-varying aberration function.

The retrieval of the local aberrations is based on the fact that spatially-varying aberrations are shift-invariant in a sufficiently small sub-region of the FOV of the imaging system. For this reason, the image of the periodic object pattern in each sub-region remains periodic. Because the pitches of the periodic image pattern match that of the periodic image, the parts of the periodic image seen through different periods of the periodic image pattern are the same. As a consequence, at each scanning step, the intensity collected by each pixel cluster in the sensor array is enhanced by a number of times, which number is equal to the number of periods in a sub-region comparing to the case in which this sub-region contains only one period.

The scanning step size and the scanning range determine the resolution and the size of the measured image of the object pattern in each sub-region. Preferably, the scanning step size is smaller than $\lambda/(4NA)$ where λ is the illumination wavelength and NA is the numerical aperture of the imaging system, and the scanning range is preferably larger than one period of the periodic image, preferably one period or an integer number of periods. The scanning step size and the scanning range is preferably chosen such that the measured image of the object pattern contains sufficient information of local aberrations.

The object mask and image mask may be identical, but this is not necessary. The size of the features of the pattern in each period is preferably smaller or at least comparable with the theoretical resolution of the imaging system, which is $\lambda/(2NA)$ where λ is the illumination wavelength and NA is the numerical aperture of the imaging system. The pitches are preferably larger or at least comparable to the size of the image generated by a point source in the object plane (this is actually a point-spread function), which is defined as the size of the area in which the value of the intensity of the point-spread function is non-negligible. The advantage of using the periodic array is that for multiple locations in the FOV (hereafter: FOV locations) the aberrations can be measured simultaneously. The number of the locations that can be measured simultaneously equals the number of the pixel clusters in the sensor array.

The object and image masks are amplitude masks or phase masks or a combination of both. In an embodiment, the first and second pitches are equal. Each sub-region includes a size of at least one pitch in both directions of the object pattern. Smaller sub-regions lead to a higher resolution of the calibration, i.e. of the spatially-varying aberration function, in terms of FOV locations. The sub-regions may overlap one another. The features of the masks may be pinholes. Alternatively, the features may be apertures of any other shape or they may be groups of apertures, or the features may be formed by materials with locally varying thickness of the mask or groups of such features. Other features that affect amplitude or phase of the radiation may be contemplated by a person skilled in the art. The pixel clusters in the sensor array may consist of a single pixel, or of a small group of pixels. Each pixel or pixel cluster of the sensor array views, through the image mask, a different sub-region of the object plane. The sizes of different sub-regions are the same and are determined by the scaling ratio of the projection optics of the image detector.

Regarding the scaling, a person skilled in the art will understand that in usual operation the object is scaled down and projected smaller in the image plane. However, the scaling ratio between object and image may be larger than 1 (i.e. object larger than image), but it may also be smaller than 1 or equal to 1.

While the optical device is especially designed for application in lithography systems, a person skilled in the art will appreciate that it can be used in a wide range of imaging systems. The radiation may be optical radiation, in the range of visible and/or ultraviolet light.

In an embodiment, the optical device is further adapted to take images at defocused planes at a side of the image plane.

Images can be taken not only in the designed nominal image plane of the imaging system but also in defocused planes slightly above or slightly below the image plane, when the image plane is oriented horizontally. To this end, the image mask and/or the object mask are is adapted to be moved in a direction along the optical axis. To retrieve the aberrations, imaging at least one defocused plane is preferred and the defocus distances relative to the image plane are determined by the specifications of the imaging system. The defocus distance is typically such that there is a significant difference between measurements in different defocused planes. However, if the defocus distance is too large, computational errors may occur. The largest useful defocus distance is calculated using the Debye formula as $5\lambda/NA^2$, where λ is the illumination wavelength and NA is the numerical aperture of the imaging system. The defocused planes are preferably chosen at symmetrical locations on both sides of the image plane. In an embodiment, the defocus distance is between 1 µm (micrometre) and 50 µm, preferably between 5 µm and 25 µm.

In an embodiment, the sensor array is electronically coupled to a processing device for processing of measured intensity values of the associated pixel clusters in the sensor array.

The processing device is adapted to perform the modelling, and associated computations, needed to retrieve the spatially-varying aberration from the images measured by the sensor array via scanning the image mask. To this end, the processing device is preferably capable of performing an optimization for searching the local aberrations which give the predictions of the images that best fit the images measured by each pixel cluster of the sensor array. This optimization can be performed in parallel or sequentially for each sub-region of the FOV.

The local aberrations may be described as a two-dimensional function of the coordinates in the pupil plane of the imaging system. It is customary to decompose the two-dimensional aberration function in a set of orthogonal polynomials to significantly reduce the number of variables in the optimization and accelerate the retrieval process.

In an embodiment, Zernike polynomials are used to decompose the aberration function. An advantage is that the Zernike polynomials are associated with particular types of aberrations. For example, the Zernike polynomial with radial order 2 and azimuthal order 0 describes the defocus aberration and the corresponding decomposition coefficient gives the amount of defocus aberration. Consequently, by retrieving the set of decomposition coefficients in each sub-region of the FOV, we can determine how each type of the aberrations varies spatially as a function of the FOV locations.

In an embodiment, the image mask is attached to a translational device that is arranged for positioning the image mask at a series of predetermined positions by translating the image mask with a predetermined step size and step number along the first and second pitch directions orthogonal to the optical axis.

By scanning the image mask in two orthogonal directions with respect to the object mask, an intensity variation can be measured as function of the scanning positions. In this way, aberrations in large number of FOV locations of the imaging system can be characterised, such that a calibration with a very high resolution is obtained. Scanning the image is more effective and more efficient than magnifying the image further, since magnification will inevitably introduce further aberrations which need to be avoided. Since the scanning step size can be as small as a few nanometres using commercially available translation devices, the images obtained by scanning also have much higher resolution than that measured by magnifying. Measuring images simultaneously at each FOV location by scanning is also more efficient; the number of FOV locations is much larger than the number of scanning positions that is required for retrieving the aberrations. In an embodiment, the step size is less than 500 nanometres (nm), preferably 200 nm or less.

In an embodiment, the image mask is configured for alignment of the image pattern with the object pattern. Improper alignment will introduce aberrations that are related to the tilt, distortion and defocus of the image plane. Therefore, proper alignment of the image pattern with the object pattern is advantageous.

In an embodiment, the sensor array is configured for capturing an image of the image mask at each predetermined position of the image mask.

In an embodiment, the optical device further comprises a controller for controlling a step size and step number of the translation device in the first and/or second pitch directions.

In an embodiment, the controller is arranged to control capturing of the image by the sensor array. When the controller is arranged to capture images, the process can be automated, which improves the user-friendliness of the optical device.

According to an aspect of the invention, there is provided a method for determining spatially-varying aberrations of an imaging system, comprising:

providing an imaging system configured for scaled projecting along an optical axis of an object pattern arranged in an object plane of the imaging system as a scaled image thereof on an image plane of the imaging system;

arranging an object mask at the object plane, wherein the object mask is provided with the object pattern, wherein the object pattern is a periodic array with features arranged with a first pitch in a first pitch direction and a second pitch in a second pitch direction;

wherein the features are adapted to change an amplitude and/or a phase of incident radiation; and wherein the periodic array is divided into sub-regions which each include at least one feature;

arranging an image mask at the image plane, the image mask being provided with an image pattern with a first pitch and second pitch, wherein the first pitch and second pitch of the image pattern correspond to the first pitch and second pitch of the object pattern scaled in accordance with a scaling ratio of the imaging system;

projecting the image pattern along the optical axis on pixels of a sensor array located at a fixed position relative to the object mask, wherein each sub-region of the image pattern is projected on an associated pixel cluster in the sensor array;

illuminating the object mask to generate radiation through the imaging system and the image mask;

scanning the image mask with respect to the object mask in two orthogonal directions which are perpendicular to the optical axis, and at each scanning position, measuring an intensity signal of the radiation on the pixels of the sensor array as function of the scanning positions of the image mask;

calculating the spatially-varying aberrations from the measured intensity signal.

The method is preferably adapted to be carried out with the optical device as described above, and features and advantages correspond to those of the optical device as far as they concern the method. Preferably, the first pitch direction is orthogonal to the second pitch direction.

In an embodiment, the method further comprises: aligning the image pattern of the image mask with the object pattern of the object mask.

In an embodiment, the method further comprises: positioning the image mask at a series of predetermined positions by translating the image mask with a predetermined step size and step number along the first and/or second pitch directions orthogonal to the optical axis. The translation of the image mask allows for characterisation of the full FOV of the imaging system.

In an embodiment, the method further comprises: capturing an image of the image pattern at each predetermined position of the image mask. In this manner the full FOV of the imaging system can be characterised, thus providing more information about the spatially-varying aberrations.

In an embodiment, the method further comprises: determining at each predetermined position of the image mask an intensity of radiation received on each associated pixel cluster of the sensor array. In this manner a high-resolution characterisation of the aberrations can be made.

In an embodiment, the image of the image pattern is captured with the image mask positioned in the nominal image plane.

In an embodiment, the image of the image pattern is captured with the image mask positioned at a defocus height at a side of the nominal image plane. The defocused images will provide extra information for determining the aberrations. In an embodiment, the defocus height is 25 μm or less for imaging system with numerical aperture 0.12 and illuminated by incoherent light at wavelength 355 nanometres.

In an embodiment, calculating the spatially-varying aberrations includes an optimization routine, which comprises for each sub-region the steps of

- initially guessing a local aberration function;
- providing system parameters of the imaging system and preferably of the optical device;
- modelling an optical response based on the guessed local aberration function and the system parameters;
- comparing the modelled optical response to the measured intensity signal;

- if the modelled optical response and measured intensity signal are not substantially identical, adjusting the local aberration function and return to the modelling step.

- if the modelled optical response and measured intensity signal are substantially identical, using the local aberration function for further measurements.

Substantially identical refers to a certain tolerance value, which defines a small deviation between the modelled optical response and the measured intensity signal. Within the tolerance value, the modelled optical response and measured intensity signal are still considered identical.

After repeating the optimization routine for each sub-region, the local aberration functions may be combined to a four-dimensional spatially-varying aberration function. Guessing the local aberration function may include using a two-dimensional array of random values, or an array of all zeros or all ones or any other choice based on experience or prior knowledge as initial guess.

The various aspects discussed in this patent can be combined in order to provide additional advantages.

Brief description of drawings

Embodiments will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts.

Figure 1 schematically shows an imaging system with an optical device according to the invention;

Figure 2 schematically shows a flowchart of a local aberration optimization method.

The figures are meant for illustrative purposes only, and do not serve as restriction of the scope or the protection as laid down by the claims.

Detailed description

Further advantages, features and details of the present invention will be explained in the following description of some embodiments thereof. In the description, reference is made to the attached figures.

Figure 1 shows a schematic view of an imaging system 10, scaled projecting an object in the object plane 11 to an image plane 14, together with an optical device 1. In this case, the optical device 1 comprises an object mask 12 which is arranged in the object plane 11. The object mask 12 comprises an object pattern 13 as shown next to it. The object pattern 13 is in this example a square pinhole array comprising a plurality of pinholes 18. The array extends in a first and second orthogonal direction x, y, which are both perpendicular to the optical axis a.

The object mask 12 is illuminated from the side facing away from the imaging system 10, such that the radiation is projected by the imaging system 10 to the image plane 14. Due to the wave character of the light, the intensity distribution of the radiation 17 is described by a convolution between the scaled object pattern and the point spread function (which gives the image of the object pattern).

The optical device 1 further comprises an image mask 15, which is arranged in the image plane 14. The image mask 15 comprises an image pattern 16, shown next to it, which is a square pinhole array comprising a plurality of pinholes 19, the array extending in a first and second orthogonal direction x, y, which are both perpendicular to the optical axis a. The pitch of the image pattern 16 corresponds to the pitch of the object pattern 13 apart from a scaling due to the imaging system 10.

The radiation transmitted through the image mask 15 is thus theoretically an overlay of the intensity distribution of the image of the object pattern 17 and the image pattern 16. The optical device 1 comprises projecting optics 20 and a pixelated sensor array 22. The projecting optics 20 is used to project the radiation transmitted through the image mask 15 onto a camera plane 21 where the sensor array 22 is placed. The sensor array 22 is capable of capturing images of the image plane, i.e., measures a signal associated with the radiation transmitted through the image mask 15. In an embodiment, the sensor array is coupled to a computer device (not shown) that is capable of processing and analysing images captured by the sensor array, in order to calculate the spatially-varying aberrations.

Since the object pattern 13 and the image pattern 16 correspond, from the measured signal by the sensor array the effect of the spatially varying aberrations can be observed. In fact, the difference between the intensity measured by different pixel cluster of the sensor array gives the evidence of spatially-varying aberrations. The optical device 1 further comprises a three-dimensional translational device 23, which is capable of moving the image mask 15 along the optical axis a and along the two orthogonal directions x, y, perpendicular to the optical axis a. It may alternatively be possible to have a two-dimensional translational device, while the optical device 1 has other means of capturing defocused images of the image plane 14, for example by having a movable object mask 12.

By scanning the image mask 15 in the two orthogonal directions x, y, perpendicular to the optical axis a, the aberrations in the full FOV of the imaging system 10 can be characterised. In fact, in each direction only scanning over the distance between two adjacent pinholes 19 will be sufficient.

At each scanning position of the image mask 15, the transmitted radiation from a certain sub-region of the FOV is projected onto a single pixel or pixel cluster 24 of the sensor array 22. In the shown example in Figure 1, this particular sub-region is formed by 7x7 periods of the image mask 15. By scanning over the distance between two adjacent pinholes 19 in each direction with a certain scanning step size, the image of the object pattern 25 at the resolution equal to the scanning step size can be captured. Local aberrations can then be calculated from such image together with other images captured with different defocus settings.

As an example, an imaging system with a numerical aperture of 0.12 is used which is illuminated with spatially incoherent light at a wavelength of 355 nm. The feature size may be a square aperture with a length of 2.5 μm and the pitch size is 4.5 μm in both orthogonal directions. The scanning step size may be 180 nm and the number of scanning steps in both directions is 25. The maximum defocus distance is 25 μm at either side of the nominal image plane.

Figure 2 shows a flowchart 100 of a possible local aberration optimization method. The method starts with an initial guess of local aberrations 101, in the form of a two-dimensional pattern that may be converted to a combination or set of Zernike polynomials. The initial guess acts as input for the modelling 102 of an optical response and the calculation of a function to update the guess. This modelling, which in an embodiment is done by a computer device as mentioned above with reference to Figure 1, takes also into account other information 103, comprising the illumination information, imaging system specifications, optical device specifications, object mask and image mask specifications, predefined scanning positions and locations of measurement planes (focused/defocused). The modelled response is compared to the measurements 104 by the sensor array in an evaluation step 105 in which an error function is evaluated, which represents the difference between the modelled response from the modelling step 102 and the measurements 104 in a particular sub-region. A choice of the error function may be influenced by the type of measurement noise. The error function may be the L2 norm of the difference between the modelled response and the measurements 104. The measurements 104 are the intensities at each predefined scanning position measured by a pixel cluster in the focal plane and preferably also in the defocused planes.

The error function is then compared to a certain tolerance value in the comparison step 106. If the error function is smaller than or equal to the tolerance value, the local aberrations 107 have been correctly determined and can be used in future measurements. If the error function is larger than the tolerance value, the guess of local aberrations was insufficient, and is updated in step 108 using the update function calculated in modelling step 102. In that event, the process of the flowchart 100 is repeated until the error function is smaller than or equal to the tolerance value. Repeating the procedure may also stop if other constraints are violated, for example by exceeding maximum number of iterations or maximum time duration.

The obtained two-dimensional local aberration functions 107 at all sub-regions from the flowchart 100 are combined to form the four-dimensional spatially-varying aberration function.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. It will be apparent to the person skilled in the art that alternative and equivalent embodiments of the invention can be conceived and reduced to practice. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

1. Optical device for measuring spatially-varying aberrations of an imaging system;
the imaging system configured for scaled projecting along an optical axis of an object pattern arranged in an object plane of the imaging system as a scaled image thereof on an image plane of the imaging system;
the optical device comprising an object mask, an image mask and an image detector;
the object mask positioned at the object plane and provided with the object pattern, wherein the object pattern is a periodic array with features arranged with a first pitch in a first pitch direction and a second pitch in a second pitch direction, preferably orthogonal to the first pitch direction;
wherein the features are adapted to change an amplitude and/or a phase of incident radiation; and wherein the periodic array is divided into sub-regions which each include at least one feature;
the image mask positioned at the image plane and provided with an image pattern with a first pitch and a second pitch, wherein the first pitch and second pitch of the image pattern correspond to the first pitch and second pitch of the object pattern, scaled in accordance with a scaling ratio of the imaging system;
the image detector comprising projection optics and a sensor array, wherein the sensor array is a pixelated sensor array at a fixed position relative to the object mask and the projection optics are arranged for projecting the image pattern along the optical axis on the sensor array, and are configured to project each sub-region of the image pattern on an associated pixel cluster in the sensor array;
and the optical device is adapted to translate the image mask and/or the object mask in a direction perpendicular to the optical axis.

2. The optical device according to claim 1, wherein the optical device is adapted to take images at a defocused plane at a side of the image plane.

3. The optical device according to claim 1 or 2, wherein the sensor array is electronically coupled to a processing device for processing of measured intensity values of the associated pixel clusters in the sensor array.

4. The optical device according to any one of the preceding claims, wherein the image mask is attached to a translational device that is arranged for positioning the image mask at a series of predetermined positions by translating the image mask with a predetermined step size and step number along the first and second pitch directions orthogonal to the optical axis.

5. The optical device according to claim 4, wherein the image mask is configured for alignment of the image pattern with the object pattern.

6. The optical device according to any one of claims 4-5, wherein the sensor array is configured for capturing an image of the image mask at each predetermined position of the image mask.

7. The optical device according to any one of claims 4-6, further comprising a controller for controlling a step size and step number of the translation device in the first and/or second pitch direction.

8. The optical device according to claim 7, wherein the controller is arranged to control capturing of the image by the sensor array.

9. Method for determining spatially-varying aberrations of an imaging system, comprising:
providing an imaging system configured for scaled projecting along an optical axis of an object pattern arranged in an object plane of the imaging system as a scaled image thereof on an image plane of the imaging system;
arranging an object mask at the object plane, the object mask being provided with the object pattern, wherein the object pattern is a periodic array with features arranged with a first pitch in a first pitch direction and a second pitch in a second pitch direction;
wherein the features are adapted to change an amplitude and/or a phase of incident radiation; and wherein the periodic array is divided into sub-regions which each include at least one feature;
arranging an image mask at the image plane, the image mask being provided with an image pattern with a first pitch and second pitch, wherein the first pitch and second pitch of the image pattern correspond to the first pitch and second pitch of the object pattern scaled in accordance with a scaling ratio of the imaging system;
projecting the image pattern along the optical axis on pixels of a sensor array located at a fixed position relative to the object mask, wherein each sub-region of the image pattern is projected on an associated pixel cluster in the sensor array;
illuminating the object mask to generate radiation through the imaging system and the image mask;
scanning the image mask with respect to the object mask in two orthogonal directions which are perpendicular to the optical axis, and at each scanning position, measuring an intensity signal of the radiation on the pixels of the sensor array as function of the scanning positions of the image mask;
calculating the spatially-varying aberrations from the measured intensity signal.

10. Method according to claim 9, further comprising: aligning the image pattern of the image mask with the object pattern of the object mask.

11. Method according to claim 9 or 10, wherein the scanning of the image mask comprises: positioning the image mask at a series of predetermined positions by translating the image mask with a predetermined step size and step number along the first and second pitch directions orthogonal to the optical axis.

12. Method according to claim 11, further comprising: capturing an image of the image pattern at each predetermined position of the image mask.

13. Method according to claim 12, further comprising: determining at each predetermined position of the image mask an intensity of radiation received on each associated pixel cluster of the sensor array.

14. Method according to claim 12 or claim 13, wherein the image of the image pattern is captured with the image mask positioned in the nominal image plane.

15. Method according to claim 12 or claim 13, wherein the image of the image pattern is captured with the image mask positioned at a defocus height at a side of the nominal image plane.

16. Method according to any one of claims 9 – 15, wherein the step of calculating the spatially-varying aberrations from the measured intensity signal comprises an optimization routine, which comprises for each sub-region the steps of
- initially guessing a local aberration function;
- providing system parameters of the imaging system;
- modelling an optical response based on the guessed local aberration function and the system parameters;
- comparing the modelled optical response to the measured intensity signal;
- if the modelled optical response and the measured intensity signal are not substantially identical, adjusting the local aberration function and return to the modelling step.
- if the modelled optical response and the measured intensity signal are substantially identical, using the local aberration function for further measurements.

Fig. 1

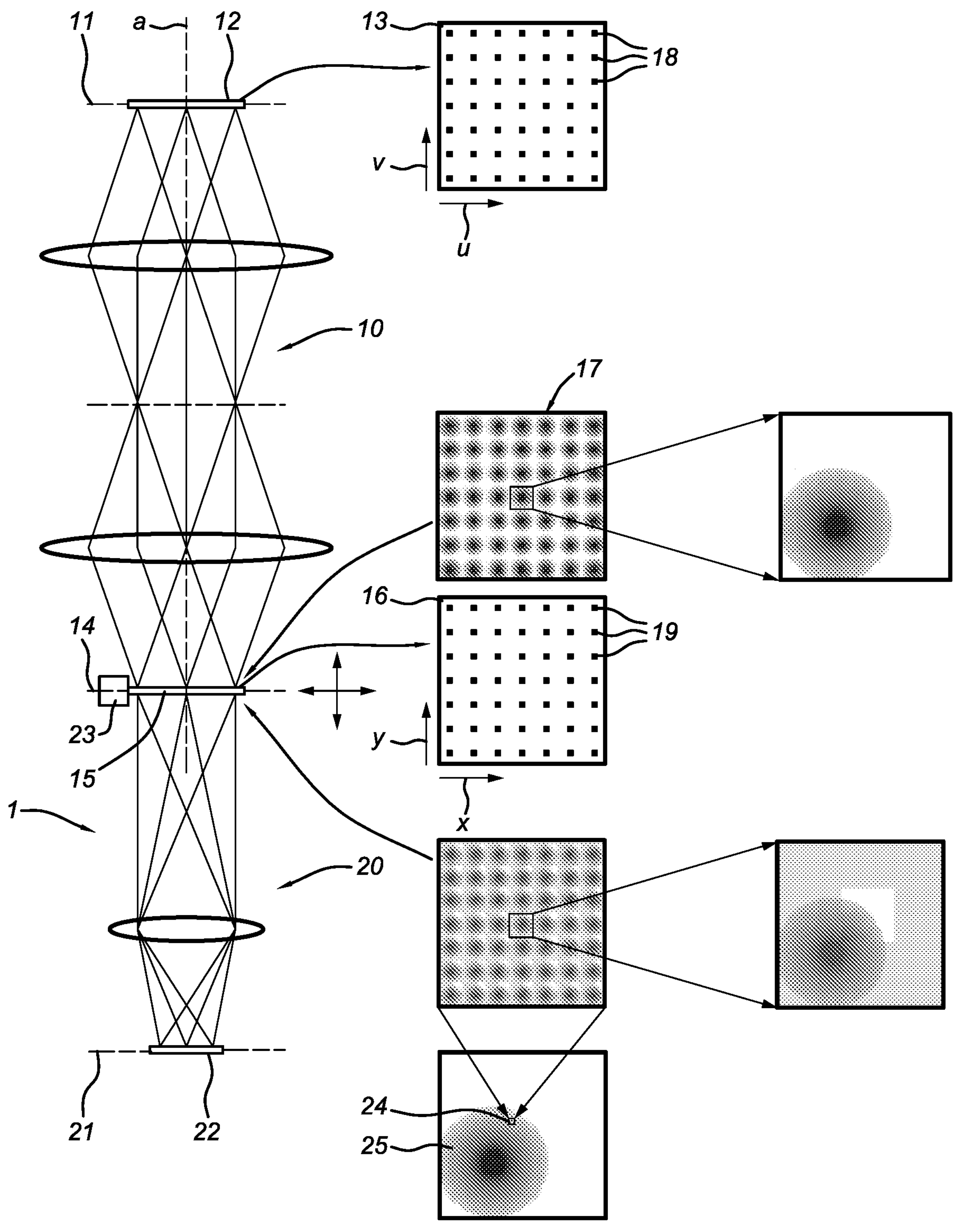
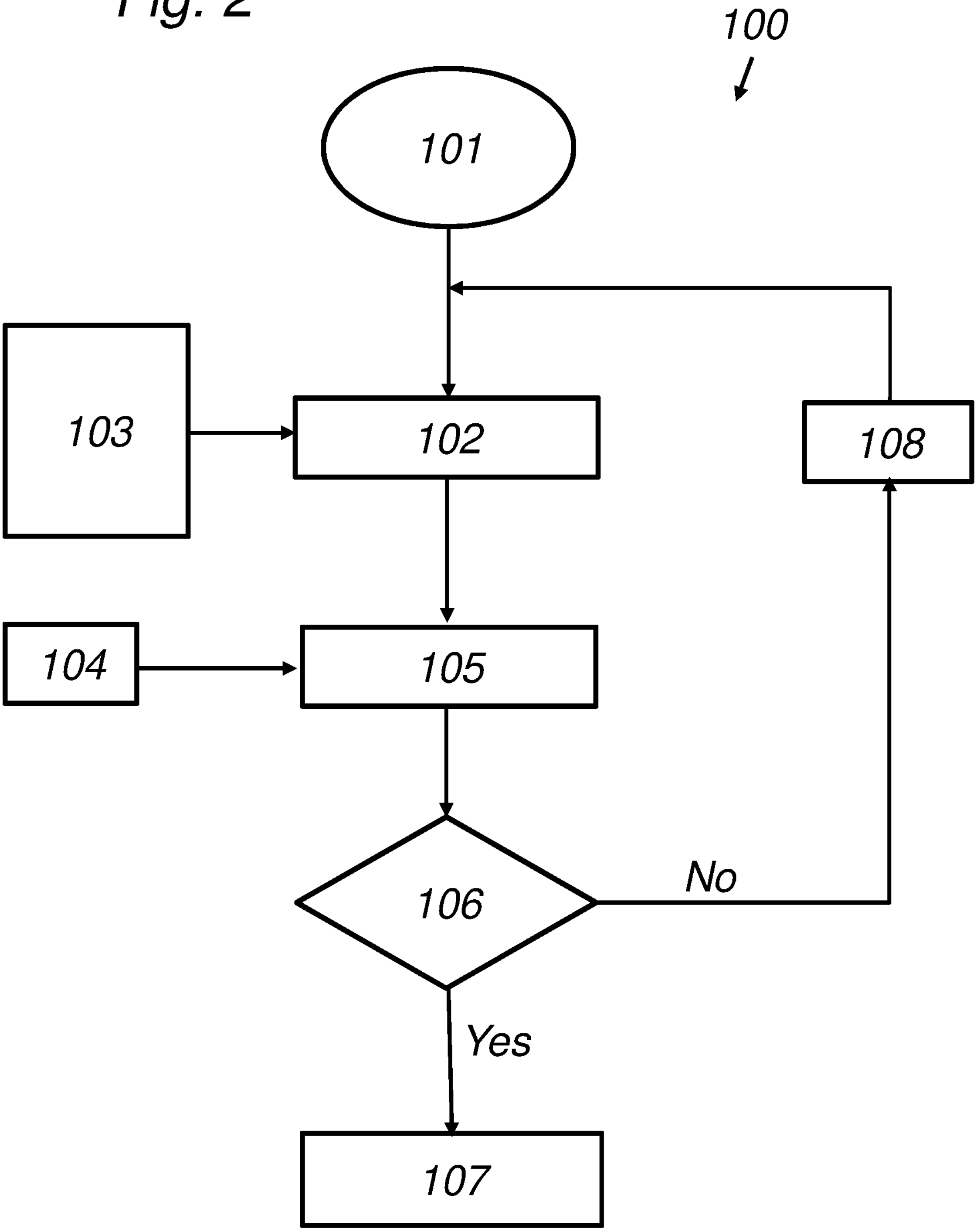


Fig. 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2019/050529

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 G01M11/02
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 G01M

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.
A	US 6 693 704 B1 (OOKI HIROSHI [JP] ET AL) 17 February 2004 (2004-02-17) column 4, line 15 - column 6, line 55; figure 1 column 7, line 45 - column 8, line 40; figures 3,4 column 12, line 22 - line 60; figures 8a,8b -----	1-16
A	JP 2005 129557 A (NIKON CORP) 19 May 2005 (2005-05-19) abstract paragraphs [0071] - [0074]; figure 7.9 -----	1-16
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 November 2019	26/11/2019

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

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/259350 A1 (FURUKAWA YASUNORI [JP]) 23 October 2008 (2008-10-23) paragraphs [0004] - [0011] paragraphs [0043] - [0049]; figures 1-3 paragraphs [0058] - [0060]; figure 6 paragraphs [0100] - [0109]; figure 24	1-16
A	US 7 019 824 B2 (ZEISS CARL SMT AG [DE]) 28 March 2006 (2006-03-28) cited in the application column 7, line 58 - column 8, line 31; figure 1	1,9
A	US 2002/191195 A1 (ICHIHARA HIROSHI [JP] ET AL) 19 December 2002 (2002-12-19) paragraphs [0112] - [0126]; figures 12,13a,13b	1,9
A	US 6 118 535 A (GOLDBERG KENNETH ALAN [US] ET AL) 12 September 2000 (2000-09-12) column 5, line 29 - column 7, line 13; figures 2,3a,3b	1,9

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NL2019/050529

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6693704	B1	17-02-2004	NONE			
JP 2005129557	A	19-05-2005	NONE			
US 2008259350	A1	23-10-2008	JP	2008192855	A	21-08-2008
			KR	20080073232	A	08-08-2008
			TW	200901274	A	01-01-2009
			US	2008259350	A1	23-10-2008
US 7019824	B2	28-03-2006	AU	2003212309	A1	22-09-2003
			EP	1483559	A2	08-12-2004
			JP	2005519299	A	30-06-2005
			US	2005122506	A1	09-06-2005
			WO	03076891	A2	18-09-2003
US 2002191195	A1	19-12-2002	US	6312373	B1	06-11-2001
			US	2001028462	A1	11-10-2001
			US	2002191195	A1	19-12-2002
			US	2003215053	A1	20-11-2003
US 6118535	A	12-09-2000	AU	5320400	A	18-12-2000
			US	6118535	A	12-09-2000
			WO	0073753	A1	07-12-2000