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(54) Title: METHOD FOR OVERLAY METROLOGY AND APPARATUS THEREOF

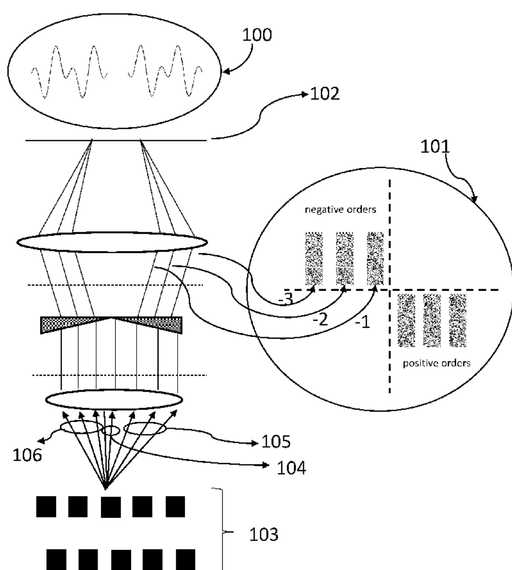

Figure 1

(57) Abstract: A method includes receiving an image formed in a metrology apparatus wherein the image comprises at least the resulting effect of at least two diffraction orders, and processing the image wherein the processing comprises at least a filtering step, for example a Fourier filter. The process of applying a filter may be obtained also by placing an aperture in the detection branch of the metrology apparatus.

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METHOD FOR OVERLAY METROLOGY AND APPARATUS THEREOF

Cross-reference to related applications

5 **[0001]** This application claims priority of US application 62/787,191 which was filed on December 31, 2018 and which is incorporated herein in its entirety by reference.

[0002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of

10 integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g., including part of, one, or several dies) on a substrate (e.g., a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent

15 target portions that are successively patterned

[0003] Significant aspects to enabling a patterning process (i.e., a process of creating a device or other structure involving patterning (such as lithographic exposure or imprint), which may typically include one or more associated processing steps such as development of resist, etching, etc.) include developing the process itself, setting it up for monitoring and control and then actually monitoring and controlling the

20 process itself. Assuming a configuration of the fundamentals of the patterning process, such as the patterning device pattern(s), the resist type(s), post-lithography process steps (such as the development, etch, etc.), it is desirable to setup an apparatus in the patterning process for transferring the pattern onto the substrates, develop one or more metrology targets to monitor the process, setup up a metrology process to measure the metrology targets and then implement a process of monitoring and/or controlling the process

25 based on measurements.

[0004] So, in a patterning process, it is desirable to determine (e.g., measure, simulate using one or more models that model one or more aspects of the patterning process, etc.) one or more parameters of interest, such as the critical dimension (CD) of a structure, the overlay error between successive layers (i.e., the undesired and unintentional misalignment of successive layers) formed in or on the substrate, etc.

30 **[0005]** It is desirable to determine such one or more parameters of interest for structures created by a patterning process and use them for design, control and/or monitoring relating to the patterning process, e.g., for process design, control and/or verification. The determined one or more parameters of interest of patterned structures can be used for patterning process design, correction and/or verification, defect detection or classification, yield estimation and/or process control.

[0006] Thus, in patterning processes, it is desirable frequently to make measurements of the structures created, e.g., for process control and verification. Various tools for making such measurements are known, including scanning electron microscopes, which are often used to measure critical dimension (CD), and specialized tools to measure overlay, a measure of the accuracy of alignment of two layers in a device. Overlay may be described in terms of the degree of misalignment between the two layers, for example reference to a measured overlay of 1nm may describe a situation where two layers are misaligned by 1nm.

[0007] Various forms of inspection apparatus (e.g., metrology apparatus) have been developed for use in the lithographic field. For example, scatterometry devices direct a beam of radiation onto a target and measure one or more properties of the redirected (e.g., scattered) radiation – e.g., intensity at a single angle of reflection as a function of wavelength; intensity at one or more wavelengths as a function of reflected angle; or polarization as a function of reflected angle – to obtain a "spectrum" from which a property of interest of the target can be determined. Determination of the property of interest may be performed by various techniques: e.g., reconstruction of the target by iterative approaches such as rigorous coupled wave analysis or finite element methods; library searches; and principal component analysis.

[0008] A further technique involves having the zeroth order of diffraction (corresponding to a specular reflection) blocked, and only higher orders are processed. Examples of such metrology can be found in PCT patent application publication nos. WO 2009/078708 and WO 2009/106279, which are hereby incorporated by reference in their entirety. Further developments of the technique have been described in U.S. patent application publication nos. US 2011-0027704, US 2011-0043791 and US 2012-0242940, each of which is incorporated herein in its entirety. Such diffraction-based techniques are typically used to measure overlay. The targets for techniques can be smaller than the illumination spot and may be surrounded by product structures on a substrate. A target can comprise multiple periodic structures, which can be measured in one image. In a particular form of such a metrology technique, overlay measurement results are obtained by measuring a target twice under certain conditions, while either rotating the target or changing the illumination mode or imaging mode to obtain separately the -1st and the +1st diffraction order intensities. The intensity asymmetry, a comparison of these diffraction order intensities, for a given target provides a measurement of target asymmetry, that is asymmetry in the target. This asymmetry in the target can be used as an indicator of overlay error.

[0009] So, as described, during the manufacturing process there is a need to inspect the manufactured structures and/or to measure one or more characteristics of the manufactured structures. Suitable inspection and metrology apparatuses are known in the art. One of the known metrology apparatuses is a scatterometer and, for example, a dark field scatterometer. U.S. patent application publication US 2016/0161864, U.S. patent application publication US 2010/0328655 and U.S. patent application publication US 2006/0066855

discuss embodiments of a photolithographic apparatus and embodiments of a scatterometer. The cited documents are herein incorporated by reference in their entirety.

[0010] Electronic devices, such as integrated circuits, are often manufactured by means of a manufacturing process in which layers are formed on top of each other on a substrate by means of several process steps. One of the process steps may be photolithography which may use electromagnetic radiation in the deep ultraviolet (DUV) spectral range or in the extreme ultraviolet (EUV) spectral range. The substrate is often a silicon wafer. The smallest dimensions of the manufactured structures are in the nanometer range.

[0011] Figure 1 depicts a schematic of an dark field scatterometer as mentioned above, and the images formed in case the imaging sensor is placed in the image plane, or in the pupil plane of the scatterometer. The image formed in the image plane is depicted in element 100, wherein the image plane is element 102. The image formed in the pupil plane is depicted in element 101. Element 103 is an overlapping grating wherein a relative shift between the top and bottom grating is formed, i.e. there is an overlay present between the two layers. Element 104 depicts the radiation impinging on the grating and the resulting 0th order or specular scattered radiation. In a dark field scatterometer this radiation is blocked by the design of the apparatus, for example by using apertures in the illumination branch, as described in previously cited prior art. Elements 105 and 106 depict the diffraction orders resulting from the scattering of the impinging branch of the 104 radiation on the target 103. 105 depicts the negative orders and 106 depicts the positive orders.

[0012] In a diffraction based metrology method and apparatus, there is a relationship between the wavelength of light, the pitch of the grating on the wafer and the NA (numerical aperture) of the optical system, in this case the metrology tool or scatterometer. If the ratio between the wavelength and the pitch is smaller than the NA of the optical system, NA multiplied by a constant, the image does not resolve the structures on the target. If, however, said ratio is larger than the NA multiplied by a constant (most cases the constant is 1), the measured image resolves the structures present on the wafer, the structures become visible. In a typical mode of operation, a dark field scatterometer does not resolve the structures/targets on the wafer, and the metrology method relies on measuring the average intensity of the obtained image. Such method is well described in the art and in the previously cited patent application. In such typical mode of operations, the pitch of the structure is comparable with the wavelength of the light.

[0013] A problem arises as the pitch of the underling target, such as element 103 in figure 1, becomes much larger that the wavelength of the imping radiation. In this case, as depicted in element 100, multiple diffraction orders are available in the pupil plane, and all contribute to the image formation in the image plane, as depicted in element 100 of figure 1. Such large pitch targets, large as defined with respect to the wavelength of the light used in the metrology apparatus, occur, for example, in metrology of 3D-NAND structures, wherein, due to limitation imposed by the specific processing conditions, the pitches of the

metrology targets are in micron ranges, wherein the wavelength of the light remains in the optical regime. Such abundance of diffraction orders leads to complex interference patterns, as depicted in element 100, complex interference patterns which are difficult to eliminate as one use state of the art overlay extraction methods, methods which rely on smooth images, as obtained when the wavelength and the pitch of the gratings are comparable.

[0014] It is an object of the current invention to provide a method which allows using state of the art overlay measurements in a regime wherein the wavelength of the radiation is smaller than the pitch of the metrology target. The method comprises obtaining an image in the image plane of the metrology detection branch, for example when the imaging sensor is placed in said image plane, and filtering the image of the contributions due to complex interference patterns of multiple non-zero diffraction orders. In an embodiment, the filter is a digital filter. In an embodiment, the digital filter is a Fourier filter, wherein only the low frequency component in an image is obtained. In an embodiment, the filter is a Fourier filter which is applied to a synthetic image obtained as a difference between the images formed by positive and negative orders. In an embodiment, an alignment step is performed between the images obtained from negative and positive orders, before the asymmetry image is obtained as a difference between the image formed by negative and positive orders. The state of the art dark field metrology methods may be further applied to the asymmetry image obtained after the digital filtering.

[0015] In an embodiment, the method comprises the steps as depicted in figure 3. Element 300 is an image obtained as described in figure 1. Element 300 may be an asymmetry image, obtained after an alignment step between positive and negative orders formed images and further subtraction of the aligned images. Step 301 depicts the filtering step which is applied to element 300. Element 302 is sketched representation of the resulting image. Element 302 is an ideal representation of the obtained signal, as in practical application one expects that the sharp corners may be rounded, and that possible nuisance signal is still present in the resulting filtered image.

[0016] In a further embodiment, the filtering of high diffraction orders is obtained by placing an aperture in the detection branch of a metrology apparatus. As the ration between the wavelength of light and the pitch of the gratings is known, and having further knowledge of the NA of the system, an aperture may be designed with a light transmitting portion allowing only single diffraction orders. In an embodiment, the diffraction orders are +1 and -1 diffraction orders. In another embodiment, the diffraction orders are +2 and -2 diffraction orders. Further combination of single order may be further imagined, depending on the type of metrology process and metrology applications. Figure 2 depicts such aperture in elements 201 and 202.

[0017] While much of the discussion has focused on target structures as metrology targets specifically designed and formed for the purposes of measurement, in other embodiments, the target may be a functional part of devices formed on the substrate. Many devices have regular, periodic structures akin to a grating.

The term “target”, “grating” or “periodic structure” of a target as used herein does not require that the applicable structure has been provided specifically for the measurement being performed.

[0018] In an embodiment, the target may be realized using a patterning device (such as a reticle or mask) designed to produce the target on a substrate (e.g., create the pattern image for projection onto a resist layer, 5 which patterned resist layer is used to form the target using subsequent processing steps such as deposition, etching, etc.)

[0019] In association with the physical structures of the targets as realized on substrates and patterning devices (such as a reticle or mask), an embodiment may include a computer program containing one or more sequences of machine-readable instructions and/or functional data describing the target design, 10 describing a method of producing a target on a substrate, describing a method of measuring a target on a substrate and/or describing a method of analyzing a measurement to obtain information about a patterning process (e.g., a lithographic process, an etching process, etc.). This computer program may be executed for example within a processing apparatus of a lithographic apparatus or lithocell or a metrology or inspection apparatus or on a stand-alone computer. There may also be provided a data storage medium (e.g., 15 semiconductor memory, magnetic or optical disk) having such a computer program stored therein. Where an existing metrology or inspection apparatus is already in production and/or in use, an embodiment can be implemented by the provision of an updated computer program product for causing a processor to perform one or more of the methods described herein. The program may optionally be arranged to control the apparatus and the like to perform a method as described herein. The program can update the lithographic 20 and/or metrology recipe for measurement of substrates. The program may be arranged to control (directly or indirectly) the lithographic apparatus for the patterning and processing of substrates.

[0020] An embodiment of the invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed herein, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored 25 therein. Further, the machine readable instruction may be embodied in two or more computer programs. The two or more computer programs may be stored on one or more different memories and/or data storage media.

[0021] One or more aspects disclosed herein may be implemented in a control system. Any control system described herein may each or in combination be operable when the one or more computer programs are 30 read by one or more computer processors located within at least one component of an apparatus. The control systems may each or in combination have any suitable configuration for receiving, processing, and sending signals. One or more processors are configured to communicate with the at least one of the control systems. For example, each control system may include one or more processors for executing the computer programs that include machine-readable instructions for the methods described above. The control systems may

include data storage medium for storing such computer programs, and/or hardware to receive such medium. So the control system(s) may operate according the machine readable instructions of one or more computer programs.

[0022] Although specific reference may have been made above to the use of embodiments in the context of optical lithography, it will be appreciated that embodiments of the invention may be used in other applications. For example, embodiments may be with imprint lithography. In imprint lithography, a topography in a patterning device defines the pattern created on a substrate. The topography of the patterning device may be pressed into a layer of resist supplied to the substrate whereupon the resist is cured by applying electromagnetic radiation, heat, pressure or a combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured. Further, the embodiments here can be used with any process that creates a structure and so could be used with, e.g., other material removal processes or with an additive process.

[0023] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g., having a wavelength of or about 365, 355, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV) radiation (e.g., having a wavelength in the range of 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[0024] Unless specifically stated otherwise, as apparent from the discussion, it is appreciated that throughout this specification discussions utilizing terms such as “processing,” “computing,” “calculating,” “determining” or the like can refer to actions or processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic processing/computing device.

[0025] It should be understood that the description and the drawings are not intended to limit the invention to the particular form disclosed, but to the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

[0026] Modifications and alternative embodiments of various aspects of the invention will be apparent to those skilled in the art in view of this description. Accordingly, this description and the drawings are to be construed as illustrative only and are for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as examples of embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed or omitted, certain features may be utilized independently, and embodiments or features of embodiments may be combined, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as

described in the following claims. Headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description.

[0027] As used throughout this application, the word “may” is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). The words “include”, “including”, and “includes” and the like mean including, but not limited to. As used throughout this application, the singular forms “a,” “an,” and “the” include plural referents unless the content explicitly indicates otherwise. Thus, for example, reference to “an” element or "a” element includes a combination of two or more elements, notwithstanding use of other terms and phrases for one or more elements, such as “one or more.” The term "or" is, unless indicated otherwise, non-exclusive, i.e., encompassing both "and" and "or." Terms describing conditional relationships, e.g., "in response to X, Y," "upon X, Y,", “if X, Y,” "when X, Y," and the like, encompass causal relationships in which the antecedent is a necessary causal condition, the antecedent is a sufficient causal condition, or the antecedent is a contributory causal condition of the consequent, e.g., "state X occurs upon condition Y obtaining" is generic to "X occurs solely upon Y" and "X occurs upon Y and Z." Such conditional relationships are not limited to consequences that instantly follow the antecedent obtaining, as some consequences may be delayed, and in conditional statements, antecedents are connected to their consequents, e.g., the antecedent is relevant to the likelihood of the consequent occurring. Further, unless otherwise indicated, statements that one value or action is “based on” another condition or value encompass both instances in which the condition or value is the sole factor and instances in which the condition or value is one factor among a plurality of factors. Unless otherwise indicated, statements that “each” instance of some collection have some property should not be read to exclude cases where some otherwise identical or similar members of a larger collection do not have the property, i.e., each does not necessarily mean each and every.

[0028] To the extent certain U.S. patents, U.S. patent applications, or other materials (e.g., articles) have been incorporated by reference, the text of such U.S. patents, U.S. patent applications, and other materials is only incorporated by reference to the extent that no conflict exists between such material and the statements and drawings set forth herein. In the event of such conflict, any such conflicting text in such incorporated by reference U.S. patents, U.S. patent applications, and other materials is specifically not incorporated by reference herein.

[0029] The foregoing description of the specific embodiments reveals the general nature of embodiments of the invention such that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein

is for the purpose of description by example, and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

[0030] The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the disclosure as described without departing from the
5 scope of the claims set out below and the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

CLAIMS

1. A method comprising:

receiving an image formed in a metrology apparatus wherein the image comprises at least the
5 resulting effect of at least two diffraction orders, and
processing the image wherein the processing comprises at least a filtering step.

2. The method according to claim 1 wherein:

the filtering step is a digital filtering step.

10

3. An aperture for a metrology apparatus comprising:

an element comprising a radiation transmissive portion wherein the radiation transmissive portion transmits a single diffraction order.

15 4. A metrology apparatus comprising:

an aperture positioned in the detection branch of the metrology apparatus;
wherein the aperture is an aperture according to claim 3.

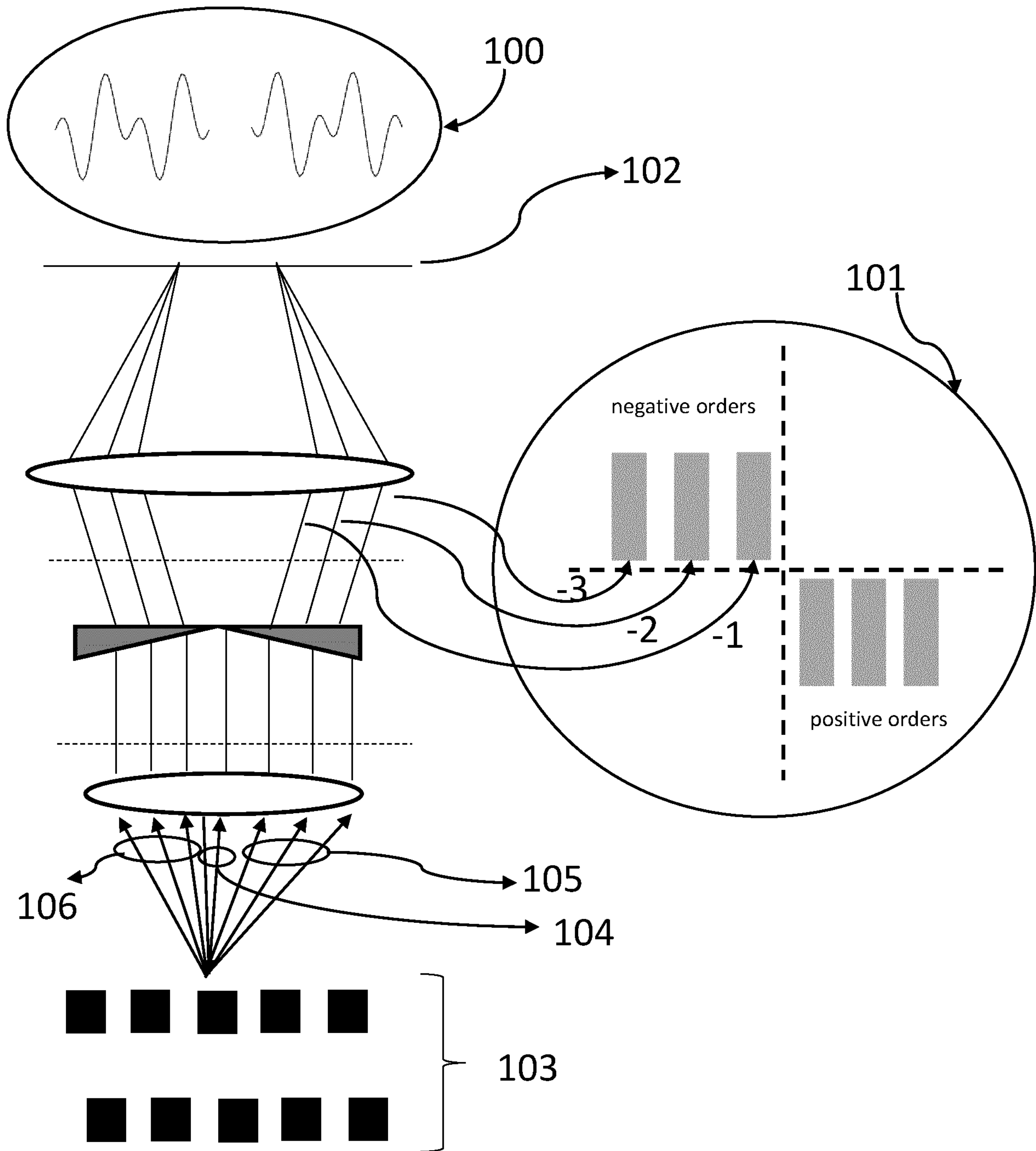

Figure 1

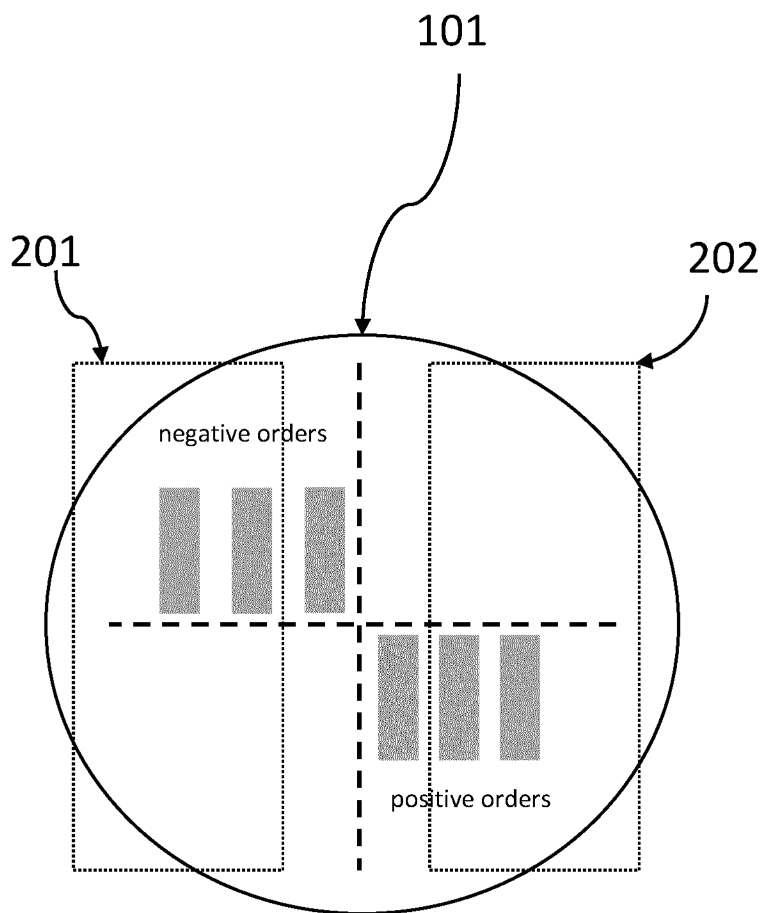

Figure 2

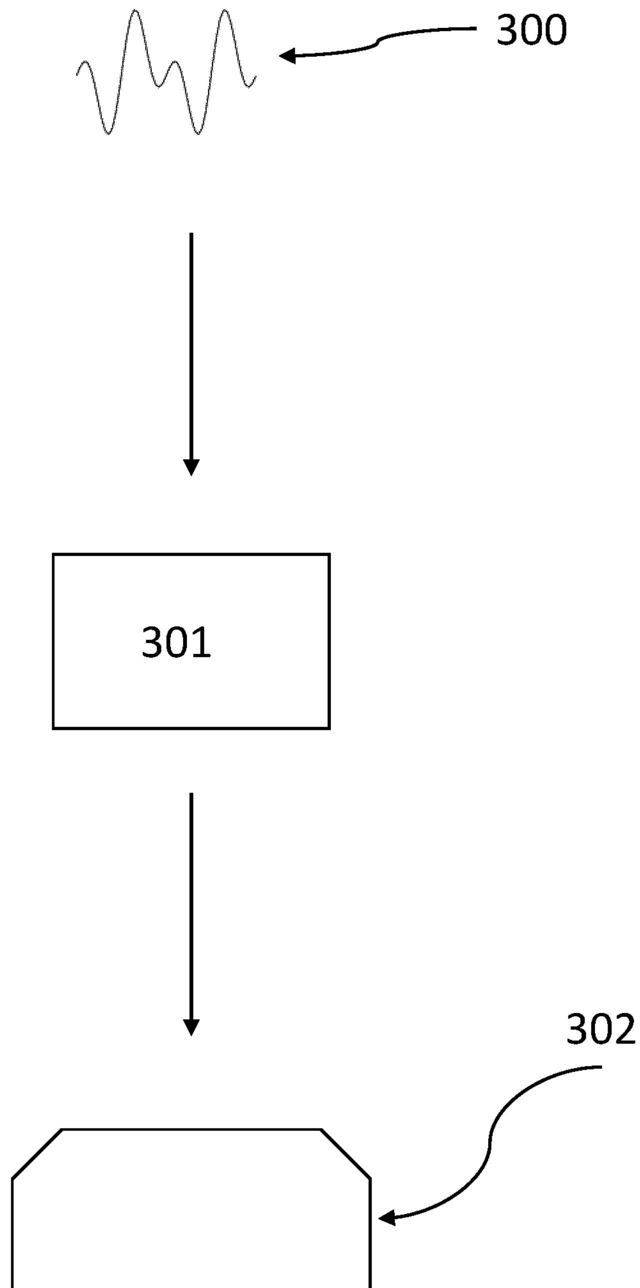

Figure 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/086222

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	WO 2016/005167 A1 (ASML NETHERLANDS BV [NL]) 14 January 2016 (2016-01-14)	1,2
A	paragraph [0106] - paragraph [0115] figures 8-10	3,4
X	US 2012/123581 A1 (SMILDE HENDRIK JAN HIDDE [NL] ET AL) 17 May 2012 (2012-05-17)	3,4
A	paragraph [0103] - paragraph [0108] figures 10,11	1,2

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 May 2020	18/05/2020

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	Meixner, Matthias

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016005167 A1	14-01-2016	CN 106662824 A	10-05-2017
		KR 20170016006 A	10-02-2017
		NL 2014994 A	12-04-2016
		TW 201606450 A	16-02-2016
		US 2016011523 A1	14-01-2016
		WO 2016005167 A1	14-01-2016
US 2012123581 A1	17-05-2012	CN 103201682 A	10-07-2013
		JP 5661194 B2	28-01-2015
		JP 2014502420 A	30-01-2014
		KR 20130094836 A	26-08-2013
		TW 201229496 A	16-07-2012
		US 2012123581 A1	17-05-2012
		US 2016033877 A1	04-02-2016
		WO 2012062858 A1	18-05-2012