



(51) International Patent Classification:
G06T 7/00 (2017.01)

(21) International Application Number:
PCT/EP2023/070638

(22) International Filing Date:
25 July 2023 (25.07.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10 2022 118 875.2
27 July 2022 (27.07.2022) DE

(71) Applicant: **CARL ZEISS SMT GMBH** [DE/DE]; Rudolf-Eber-Straße 2, 73447 Oberkochen (DE).

(72) Inventors: **KLOCHKOV, Dmitry**; Rektor-Klaus-Straße 40, 73525 Schwaebisch Gmuend (DE). **FOCA, Eugen**; Barbara-Stech-Weg 10, 73479 Ellwangen (DE).

(74) Agent: **STICHT, Andreas**; Kraus & Weisert Patentanwälte PartGmbB, Thomas-Wimmer-Ring 15, 80539 München (DE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG,

KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— with international search report (Art. 21(3))

(54) Title: METHOD FOR DISTORTION MEASUREMENT AND PARAMETER SETTING FOR CHARGED PARTICLE BEAM IMAGING DEVICES AND CORRESPONDING DEVICES

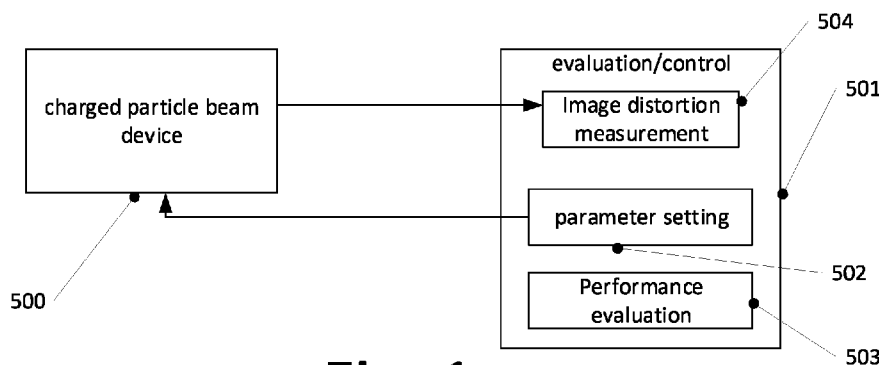


Fig. 1

(57) Abstract: A method for determining a measure of an image distortion of a charged particle beam imaging device (500) is provided. The method comprises providing a plurality of images of a region of a sample using the charged ion beam device (500), and determining the measure of the image distortion based on displacements of corresponding objects between the plurality of images. A method of setting one or more parameters of a charged particle beam imaging device (500) based on a measure of the image distortion as well as corresponding devices and systems are also provided.

Description

5 Method for distortion measurement and parameter setting for charged particle beam
 imaging devices and corresponding devices

CROSS-REFERENCE TO RELATED APPLICATION

10 The present application claims the benefit and priority of German patent application file
 number DE 10 2022 118 875.2, filed July 27, 2022, the whole content of which is
 incorporated by reference herein.

TECHNICAL FIELD

15 The present application relates to methods for measuring distortion in images captured by
 a charged particle beam imaging device, to methods of setting parameters of the charged
 particle beam imaging device based on the measure of the distortion, and to
 corresponding systems including charged particle beam imaging devices.

20

BACKGROUND

Semiconductor structures are amongst the finest man-made structures and suffer from
different imperfections. Devices for quantitative 3D-metrology, defect-detection or defect
25 review are looking for these imperfections. Fabricated semiconductor structures are based
on prior knowledge. The semiconductor structures are manufactured from a sequence of
layers being parallel to a substrate. For example, in a logic type sample, metal lines are
running parallel in metal layers or HAR (high aspect ratio) structures and metal vias run
perpendicular to the metal layers. The angle between metal lines in different layers is
30 either 0° or 90°. On the other hand, for VNAND type structures it is known that their cross-
sections are circular on average.

A semiconductor wafer has a diameter of 300 mm and consist of a plurality of several
sites, so called dies, each comprising at least one integrated circuit pattern such as for
35 example for a memory chip or for a processor chip. During fabrication, semiconductor
wafers run through about 1000 process steps, and within the semiconductor wafer, about

100 and more parallel layers are formed, comprising the transistor layers, the layers of the middle of the line, and the interconnect layers and, in memory devices, a plurality of 3D arrays of memory cells. Dimensions, shapes and placements of the semiconductor structures and patterns are subject to several influences. In manufacturing of 3D-Memory
5 devices, the critical processes are currently etching and deposition. Other involved process steps such as the lithography exposure or implantation also have an impact on the properties of the IC-elements.

The aspect ratio and the number of layers of integrated circuits constantly increases and the structures are growing into 3rd (vertical) dimension. The current height of the memory
10 stacks is exceeding a dozen of microns. In contrast, the features size is becoming smaller. The minimum feature size or critical dimension is below 10nm, for example 7nm or 5nm, and is approaching feature sizes below 3 nm in near future. While the complexity and dimensions of the semiconductor structures are growing into the 3rd dimension, the lateral dimensions of integrated semiconductor structures are becoming smaller. Therefore,
15 measuring the shape, dimensions and orientation of the features and patterns in 3D and their overlay with high precision becomes challenging.

A common way to analyze such semiconductor devices is the use of charged particle beam imaging devices and systems like scanning electron microscopy (SEM) systems,
20 which use one or more charged particle beams, in case of SEM systems electron beams, to scan the sample. SEM systems using more than one electron beam, also referred to as Multi-SEM, may have advantages for example with respect to throughput.

With the increasing requirement to the resolution of charged particle imaging systems in
25 three dimensions, the inspection and 3D analysis of integrated semiconductor circuits in wafers becomes more and more challenging. The lateral measurement resolution of charged particle systems is typically limited by the sampling raster of individual image points or dwell times per pixel on the sample, and the charged particle beam diameter. The sampling raster resolution can be set within the imaging system and can be adapted
30 to the charged particle beam diameter on the sample. The typical raster resolution is 2nm or below, but the raster resolution limit can be reduced with no physical limitation. The charged particle beam diameter has a limited dimension, which depends on the charged particle beam operation conditions and lens. The beam resolution is limited by
approximately half of the beam diameter. The resolution can be below 2nm, for example
35 even below 1nm.

A common way to generate 3D tomographic data from semiconductor samples on nm scale is the so-called slice and image approach elaborated for example by a dual beam device. A slice and image approach is described in WO 2020 / 244795 A1. According the method of the WO 2020 / 244795 A1, a 3D volume inspection is obtained at an inspection
5 sample extracted from a semiconductor wafer. This method has the disadvantage that a wafer has to be destroyed to obtain an inspection sample of block shape. This disadvantage has been solved by utilizing the slice and image method under a slanted angle into the surface of a semiconductor wafer, as described in WO 2021 / 180600 A1. According this method, a 3D volume image of an inspection volume is obtained by slicing
10 and imaging a plurality of cross-section surfaces of the inspection volume. In a first example for a precise measurement, a large number N of cross-section surfaces of the inspection volume is generated, with the number N exceeding 100 or even more image slices. For example, in a volume with a lateral dimension of 5µm and a slicing distance of 5nm, 1000 slices are milled and imaged. This method is very time consuming and can
15 require several hours for one inspection site. According several inspection tasks, it is not required to obtain a full 3D volume image. The task of the inspection is to determine a set of specific parameters of semiconductor objects such as high aspect ratio (HAR) – structures inside the inspection volume. For the determination of the set of specific parameters, the number of image slices through a volume can be reduced. WO 2021 /
20 180600 A1 illustrates some methods which utilizes a reduced number of images slices. In an example, the method applies a-priori information. From a single cross-section surface and a 3D volume image of a previous determination step, a property an HAR structures is derived.

25 For proper evaluation, the images captured need to fulfil strict requirements with respect to image distortion. Image distortion may lead to artefacts in the images, which may for example be confused with defects of the device structures itself. WO2021/180600 A1 applies a model based correction to image data, for example by extracting typical model distortion polynomials from images. Typical model distortion polynomials are selected
30 according to an imaging setup. For example, a keystone distortion may be considered under oblique imaging conditions in a slice-and-image approach with wedge-cut geometry.

This approach, however, may be inaccurate in some circumstances. For example, there is
35 the risk of a subtraction of real defects of semiconductor features (i.e. real defects are considered as distortions and removed), or distortion may be introduced by subtraction of

a too large distortion pattern from the image, corresponding to an overcorrection. The risk of inadvertently modifying the data to be measured, i.e. the images, by subtraction of model based distortions increase with the magnitude of the distortion of the imaging process.

5

DE 10 2021 130 710 A1 discloses adjustment of a particle beam microscope, in particular of a beam position. Images are captured with different focus settings, and if the particle beam is not adjusted correctly, an offset between images occurs.

- 10 DE 10 2021 200 799 B3 discloses a method for adjusting the focus setting of a particle beam microscope to take a tilt of the image plane into account.

To improve the distortion or at least keep the distortion of the images at an acceptable level, there is a need to provide a measure for the distortion. Furthermore, based on such
15 a measure, there is a need to improve the distortion.

SUMMARY

- According to a first aspect, a method for determining a measure of an image distortion of
20 a charged particle beam imaging device is provided, the method comprising:
providing a plurality of images of a region of a sample using the charged ion beam device,
and
determining the measure of the image distortion based on displacements of
corresponding objects between the plurality of images.

25

- A measure of an image distortion refers to one or more values that quantify or
characterize the image distortion. With the above method, such a measure may be
provided based on images captured e.g. from a test sample. The measure may be used
for monitoring purposes or for controlling the charged particle beam imaging device. The
30 image distortion may in particular be an image distortion based on a mechanical drift of
the system.

- In some embodiments, determining the measure of the image distortion based on the
displacement may comprise identifying corresponding objects in the plurality of images,
35 and measuring the coordinates of the objects in the images. Corresponding objects
means the same object, e.g. the same structure, but in different images.

The plurality of images may be captured with the same focus settings, e.g. same nominal focus setting. The nominal focus setting is the focus setting set by a controller. In such a case, changes between the images may in particular be caused by a mechanical drift of components of the device or also vibrations.

In some embodiments, the method may comprise, prior to the identifying of corresponding objects and measuring objects coordinates, aligning the plurality of images. This may remove or average out effects affecting the complete images in the same manner.

In some embodiments, for determining the measure of the image distortion based on the displacement, the method may further include fitting a transformation to the coordinates of corresponding objects for pairs of images of the plurality of images, and determining a maximum displacement value for each pair based on the fitted transformations. Through the use of the transformations, like affine transformations, errors in determining the coordinates may be at least partially eliminated.

In some embodiments, the pairs may include temporally adjacent pairs, i.e. pairs of images captured by the charged particle beam imaging device immediately one after the other in time. In other embodiments, other pairs, for example all possible pairs of images, may be used.

In some embodiments, the method may further comprise determining the measure of the image distortion as a function of the maximum displacement values for the different pairs. In other words, the measure is determined based on a plurality of the maximum displacement values mentioned above.

In some embodiments, the function may be selected from the group consisting of a maximum determining function (yielding the maximum of all maximum displacement values), in minimum determining function (yielding the minimum of all maximum displacement values), an averaging function (yielding the average of all maximum displacement values), and a median function (yielding the median of all maximum displacement values).

In some embodiments, the method may furthermore comprise normalizing the measure of the image distortion to a size of the portion of the sample captured by the images, also

referred to as real dimension of the images, i.e. the dimensions the portion of the sample captured in the image has in reality. In this way, measures of the image distortion for different sizes of the portion become comparable.

- 5 In some embodiments, the charged particle beam imaging device may be a multi-beam scanning electron microscope, which may enable a high throughput by the use of multiple beams.

According to a second aspect, a method of controlling a charged particle beam imaging
10 device is provided, comprising:
providing a measure of an image distortion of the charged particle beam imaging device,
and
setting at least one parameter of the charged particle beam imaging device based on the
measure of the image distortion.

15 In this way, in some embodiments one or more parameters of the charged particle beam device may be optimized. The setting of the at least one parameter may be performed automatically or may be performed at least partially based on user input, where the method automatically provides assistance to the user, for example by displaying the
20 measure of the distortion depending on the parameter to be set.

In some embodiments, in the method of the second aspect the measure of the image distortion may be provided with any of the methods of the first aspect.

25 In some embodiments, the providing of the measure of the image distortion may be performed for a plurality of values of the at least one parameter, and wherein the at least one parameter is set based on a threshold distortion. In this way, in some embodiments an image distortion smaller than indicated by the threshold distortion may be obtained.

30 In some embodiments, the at least one parameter may comprise at least one of a frame rate, a dwell time, an image resolution, a beam current, a sample mounting parameter, a milling parameter, and imaging angle of the charged particle beam imaging device and a scanning parameter of the charged particle beam imaging device. Therefore, various parameters may be optimized. Some of these parameters may be used to balance a
35 higher mechanical drift, e.g. a higher frame rate (less time for a single image) makes the images less prone to effects from mechanical drift.

In some embodiments, setting the at least one parameter may further be based on a predefined signal to noise ratio threshold. In this way, signal to noise ratio of the images may additionally be taken into account.

5

In some embodiments, the parameter may comprise an image resolution, wherein the image resolution is selected to satisfy both a threshold for the distortion and the predefined signal to noise ratio threshold. By setting the image resolution, a dwell time for individual pixels may be selected to achieve a required signal to noise ratio, and a frame
10 time for acquiring an image may be selected to achieve a required distortion. Therefore, a balance may be found between different requirements, in particular signal-to-noise ratio, where a higher dwell time is advantageous, and distortion, where a shorter time for capturing an image (i.e. higher frame rate) may be helpful.

15 According to a third aspect, a device is provided, comprising:

a controller configured to:

receive a plurality of images of a region of a sample using a charged ion beam device,
and

determine a measure of an image distortion based on displacements of corresponding
20 objects between the plurality of images.

According to a fourth aspect, a device is provided, comprising:

a controller configured to:

provide a measure of an image distortion of a charged particle beam imaging device, and

25 set at least one parameter of the charged particle beam imaging device (500; 1000) based on the measure of the image distortion.

In some embodiments, the devices of the third and fourth aspects may be configured to perform any of the methods of the first and second aspect. The explanations given above
30 for the methods also apply to the devices.

Furthermore, a system is provided, comprising:

any device of the third and/or fourth aspect, and

a charged particle beam imaging device.

35

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a device according to an embodiment.

5 Fig. 2 is a flowchart of a method according to an embodiment.

Fig. 3 is a diagram of an example charged particle beam imaging device.

10 Fig. 4 is a perspective view for explaining operation of the charged particle beam imaging device of Fig. 3.

Fig. 5 illustrates example images of semiconductor structures.

15 Fig. 6 illustrates an example image of a semiconductor structure.

Fig. 7 is a flowchart illustrating a method according to an embodiment.

Fig. 8 is a diagram illustrating a relationship between frame time and distortion.

20 Fig. 9 is a diagram illustrating a relationship between measurement accuracy and frame time.

Fig. 10 is a diagram illustrating optimization of the dwell time.

25 Fig. 11 is a diagram illustrating optimization of the frame time.

DETAILED DESCRIPTION

In the following, various embodiments will be described referring to the attached drawings.

30 These embodiments are given by way of example only and are not to be construed as limiting in any way.

Features from different embodiments may be combined to form further embodiments.

Variations, modifications and details described with respect to the one of the
35 embodiments are also applicable to other embodiments and will therefore not be described repeatedly.

In the drawings, corresponding elements are denoted with the same reference numerals.

Fig. 1 illustrates an inspection system, e.g. wafer inspection system, according to an embodiment. The system of Fig. 1 includes a charged particle beam imaging device 500 configured to provide images of semiconductor structures formed on a wafer, for example HAR-structures mentioned above. In other embodiments, instead of semiconductor structures formed on a wafer or a chip die, masks used for manufacturing semiconductor devices may be inspected. However, in the following semiconductor structures will be used as non-limiting examples. Charged particle beam imaging device 500 in various embodiments may be a scanning electron microscopy (SEM) device, as described and mentioned in the introductory portion or as described further below referring to Figures 3 and 4. Other charged particle beam imaging devices known to the skilled person may also be used, for example devices using ion beams instead of electron beams.

Charged particle beam imaging device 500 provides images of the semiconductor structures. In some embodiments, this may include a milling process, to provide a 3-dimensional tomography of the semiconductor devices.

Images captured by charged particle beam imaging device 500 may include image distortions. Image distortions in charged particle beam imaging devices are mainly caused by three factors:

(i) Distortions caused by the configuration of the charged particle beam imaging device itself, in particular the part responsible for the imaging, for example the so-called imaging column. Such distortions may be similar to or correspond to optical aberrations. They may for example be caused by the scanning process (scanning distortion), or a distortion from a specific geometry of the imaging process.

(ii) Charging of the sample to be examined, for example of semiconductor structures thereon. This distortion source depends on pre-charging conditions and from an actual accumulated charge during a measurement process. Local sample charges typically disappear due to diffusion processes after a short time. As the imaging of a charged particle beam imaging device relies, as the name says, on charged particles, charge on the sample can influence the image, i.e. cause distortions.

Pre-charging can be minimized by a slice-and-image process and charge accumulation can be mitigated by adapted scanning strategies, for example by an interlaced scanning of separated lines, such that neighboring scanning lines are only scanned after a decay time of locally accumulated charges. In other words, such a strategy tries to avoid that a current measurement at a current scanning position is overly influenced by previous measurements at previous scanning positions, which cause a charging.

(iii) Mechanical drift of the sample during the image acquisition. This means that during image acquisition, the sample may move, for example due to acoustic noise and the like. For example, vibrations may cause a movement of a stage on which the wafer is mounted, of the imaging system (scanner, scanning optics etc.) or both.

While the cause (i) above is comparatively constant based on the geometry and implementation of the charged particle beam imaging device 500 and therefore comparatively easily compensated mathematically, and the charging of the sample/wafer under (ii) can be mitigated by some strategies, dealing with mechanical drift may be more difficult, as for example vibrations causing mechanical drift may also depend on the environment.

Charged particle beam imaging device 500 is coupled to an evaluation/control device 501, for example a computer or other processing system. Evaluation/control device 501 may control charged particle beam imaging device 500 to capture a series of images of the same objects (for example semiconductor structures), possibly with milling steps beforehand or in between. Based on the series of images, indicated by block 504 evaluation/control device 501 performs an image distortion measurement, i.e. provides one or more measurement values characterizing the distortion. Such one or more measurement values characterizing the distortion will be referred to as “measure of the image distortion” or short “measure of the distortion” herein.

In some embodiments, the measure of the distortion may be used to monitor the wafer inspection process, and in case the measure of the distortion for example becomes too high indicating a high distortion, measurements may be classified as not reliable. In other words as indicated by a block 503, evaluation/control device 501 evaluates the performance of charged particle beam imaging device 500 based on the measure of the distortion. Additionally or alternatively, in other embodiments, as indicated by a block 502, evaluation/control device 501 may set parameters of charged particle beam imaging

device 500 based on the measure of the distortion, for example in order to reduce the distortion. Such parameters to be set may include for example a beam current of the charged particle beam, an acceleration voltage, a dwell time, i.e. how long the beam remains at one place for measurement, a frame time (i.e. how long it takes to capture a frame), an image resolution, also referred to as frame resolution, scanning parameters etc. By providing the measure of the distortion, optimization of these parameters to find a “sweet spot” in the parameter space may be facilitated.

Detailed implementation possibilities of the image distortion measurement and the setting of parameters as well as an example implementation of charged particle beam imaging device 500 will be explained further below.

Fig. 2 is a flow chart illustrating a method according to an embodiment, corresponding to the operation of the inspection system of Fig. 1. The method of Fig. 2 therefore may be implemented in the system of Fig. 1 or in the systems and devices discussed below.

At a step 600, the method comprises capturing a series of images using a charged particle beam imaging device, for example using charged particle beam imaging device 500 of Fig. 1, of a sample. The images include the same or corresponding structures. In some embodiments, the sample may be a test wafer or test sample specifically used for determining the distortion.

At a step 601, a measure of the image distortion is determined as explained above. For determining the measure of the image distortion, for example displacements of corresponding objects between images in the series of images may be used.

At a step 602, the method comprises setting parameters of the charged particle beam imaging device, for example charged particle beam imaging device 500, based on the measure of the distortion.

At a step 603, the method comprises evaluating the performance based on the measure of the distortion, for example to detect when the distortion is at an acceptable value.

Step 602 and 603 may both be performed, or only one of them may be performed. In some embodiments, the method is performed repetitively, for example for evaluating the performance in step 603 in regular or irregular intervals. In some embodiments, during a first run step 602 may be performed to set parameters, and then in subsequent runs step

603 may be performed. In case in step 603 the measure then indicates an unacceptable distortion, the method may be repeated with step 602, to readjust the parameters.

Next, example implementations of the system of Fig. 1 and the method of Fig. 2 will be described. Other implementations may also be used.

First, referring to Figures 3 and 4, an example implementation of charged particle beam imaging device 500 will be described. Other implementations, for example other charged particle beam imaging devices, may also be used.

An example charged particle beam imaging device 1000 for 3D volume inspection is illustrated in Fig. 3, which is an example for charged particle beam imaging device 500 of Fig. 1. The charged particle beam imaging device 1000 is configured for a slice and imaging method under wedge cut geometry with a dual beam device 1. For a wafer 8, several measurement sites, comprising measurement sites 6.1 and 6.2, are defined in a location map or inspection list generated from an inspection tool or from design information. The wafer 8 is placed on a wafer support table 15. The wafer support table 15 is mounted on a stage 155 with actuators and position control. Movement of stage 155, for example due to vibrations, is an example cause for image distortions. Actuators and means for precision control for a wafer stage such as laser interferometers are known in the art. A control unit 16 configured to control the wafer stage 155 and to adjust a measurement site 6.1 of the wafer 8 at the intersection point 43 of the dual-beam device 1. Control unit 16 may be implemented together with evaluation/control device 501 of Fig. 1, or may be a separate control unit. The dual beam device 1 comprises a FIB column 50 with a FIB optical axis 48 and a charged particle beam (CPB) imaging system 40 with optical axis 42. Vibration or other displacement of FIB column 50 and/or CPB imaging system 40 may also cause image distortions.

At the intersection point 43 of both optical axes of FIB and CPB imaging system, the wafer surface is arranged at a slant angle GF to the FIB axis 48. FIB axis 48 and CPB imaging system axis 42 include an angle GFE and the CPB imaging system axis forms an angle GE with normal to the wafer surface 55. In the coordinate system of Fig. 3, the normal to the wafer surface 55 is given by the z-axis.

The focused ion beam (FIB) 51 is generated by the FIB-column 50 and is impinging under angle GF on the surface 55 of the wafer 8. Slanted cross-section surfaces are milled into

the wafer by ion beam milling at the inspection site 6.1 under approximately the slant angle GF. In the example of Fig. 3, the slant angle GF is approximately 30°. The actual slant angle of the slanted cross-section surface can deviate from the slant angle GF by up to 1° to 4° due to the beam divergence of the focused ion beam, for example a Gallium-Ion beam. With the charged particle beam imaging system 40, inclined under angle GE to the wafer normal, images of the milled surfaces are acquired. In the example of Fig. 3, the angle GE is about 15°. However, other arrangements are possible as well, for example with GE = GF, such that the CPB imaging system axis 42 is perpendicular to the FIB axis 48, or GE = 0°, such that the CPB imaging system axis 42 is perpendicular to the wafer surface 55.

During imaging, a beam of charged particles 44 is scanned by a scanning unit of the charged particle beam imaging system 40 along a scan path over a cross-section surface of the wafer at measurement site 6.1, and secondary particles as well as scattered particles are generated. Particle detector 17 collects at least some of the secondary particles and scattered particles and communicates the particle count with a control unit 19. Other detectors for other kinds of interaction products may be present as well. Control unit 19 is in control of the charged particle beam imaging column 40, of FIB column 50 and connected to a control unit 16 to control the position of the wafer mounted on the wafer support table via the wafer stage 155. Control unit 19 communicates with operation control unit 2, which triggers placement and alignment for example of measurement site 6.1 of the wafer 8 at the intersection point 43 via wafer stage movement and triggers repeatedly operations of FIB milling, image acquisition and stage movements. Control units 19, 16, 2 may be implemented as separate entities, or may be integrated in a single control device, and/or may be integrated with or separate from device 501 of Fig. 3.

Each new intersection surface is milled by the FIB beam 51, and imaged by the charged particle imaging beam 44, which is for example scanning electron beam or a Helium-Ionbeam of a Helium ion microscope (HIM).

In an example, the dual beam system comprises a first focused ion beam system 50 arranged at a first angle GF1 and a second focused ion column arranged at the second angle GF2, and the wafer is rotated between milling at the first angle GF1 and the second angle GF2, while imaging is performed by the imaging charged particle beam column 40, which is for example arranged perpendicular to the wafer surface.

Fig. 4 illustrate further details of the slice and imaging method in the wedge cut geometry. By repetition of the slicing and imaging method in wedge-cut geometry, a plurality of J cross-section image slices comprising image slices of cross-section surfaces 52, 53.i... 53.J is generated and a 3D volume image of an inspection volume 160 at an inspection site 6.1 of the wafer 8 at measurement site 6.1 is generated. Fig. 4 illustrates the wedge cut geometry at the example of a 3D-memory stack. The cross-section surfaces 53.1... 53.N are milled with a FIB beam 51 at an angle GF of approximately 30° to the wafer surface 9, but other angles GF, for example between $GF = 20^\circ$ and $GF = 60^\circ$ are possible as well. Fig. 4 illustrates the situation, when the surface 52 is the new cross-section surface which was milled last by FIB 51. The cross-section surface 52 is scanned for example by SEM beam 44, which is in the example of Fig. 4 arranged at normal incidence to the wafer surface 55, and a high-resolution cross-section image slice is generated. The cross-section image slice comprises first cross-section image features, formed by intersections with high aspect ratio (HAR) structures or vias (for example first cross-section image features of HAR-structures 4.1, 4.2, and 4.3) and second cross-section image features formed by intersections with layers L.1 ... L.M, which comprise for example SiO₂, SiN- or Tungsten lines. Some of the lines are also called "word-lines". The maximum number M of layers is typically more than 50, for example more than 100 or even more than 200. The HAR-structures and layers extend throughout most of the volume in the wafer but may comprise gaps. The HAR structures typically have diameters below 100nm, for example about 80nm, or for example 40nm. The cross-section image slices contain therefore first cross-section image features as intersections or cross-sections of the HAR structure footprints at different depth (Z) at the respective XY-location.

In case of vertical memory HAR structures of a cylindrical shape, the obtained first cross-sections image features are circular or elliptical structures at various depths determined by the locations of the structures on the sloped cross-section surface 52. The memory stack extends in the Z-direction perpendicular to the wafer surface 55. The thickness d or minimum distances d between two adjacent cross-section image slices is adjusted to values typically in the order of few nm, for example 30nm, 20nm, 10nm, 5nm, 4nm or even less. Once a layer of material of predetermined thickness d is removed with FIB, a next cross-section surface 53.i... 53.J is exposed and accessible for imaging with the charged particle imaging beam 44.

Figure 5 illustrates an i th and $(i+1)$ -th cross-section image slice at an example. The vertical HAR structures appear in the cross-section image slices as first cross-section image features, for example first cross-section image features 77.1, 77.2 and 77.3. Since the imaging charged particle beam 44 is oriented parallel to the HAR structures, the first cross-section image features representing for example an ideal HAR structures would appear at same y-coordinates. For example, first cross-section image features of ideal HAR structures 77.1 and 77.2 are centered at line 80 with identical Y coordinate of the i th and $(i+1)$ -th image slice. The cross-section image slices further comprise a plurality of second cross-section image features of a plurality of layers comprising for example layers L1 to L5, for example second cross-section image features 73.1 and 73.2 of layer L4. The layer structure appears as segments of stripes along X-direction in the cross-section image slices. The position of these second cross-section image features representing the plurality of layers, here shown layers L1 to L5, however, changes with each cross-section image slice with respect to the first cross-section image features. As the layers intersect the image planes at increasing depth, the position of the second cross-section image features changes from image slice i to image slice $i+1$ in a predefined manner. The upper surface of layer L4, indicated by reference numbers 78.1, 78.2, are displaced by distance D2 in y direction. From determining the positions of the second cross-section image features, for example 78.1 and 78.2, the depth map $Z(x,y)$ of a cross-section image can be determined. By feature extraction of the second cross-section image features, such as edge detection or centroid computation and image analysis, and according the assumption of the same or similar depth of the second cross-section image features, the determination of the lateral position as well as the relative depth of the first cross-section image features in cross-section image slices is therefore possible with high precision. Due to the planar fabrication techniques involved in the fabrication of a wafer, layers L1 to L5 are at constant depth over a larger area of a wafer. The depth maps of first cross-section image slices can at least be determined relative the depth of second cross-section images features in the M layers. Further details for the generation of the depth maps $ZJ(x,y)$ for the cross-section image slices are described in WO 2021 / 180600 A1.

A plurality of J cross-section image slices acquired in this manner covers an inspection volume of the wafer 8 at measurement site 6.1 and is used for forming of a 3D volume image of high 3D resolution below for example 10nm, preferably below 5nm. The inspection volume 160 (see Fig. 4) typically has a lateral extension of $LX = LY = 5\mu\text{m}$ to $15\mu\text{m}$ in x-y plane, and a depth LZ of $2\mu\text{m}$ to $15\mu\text{m}$ below the wafer surface 55. The full 3D volume image generation according WO 2021 / 180600 A1 typically requires the

milling of cross-section surfaces into the surface 55 of the wafer 8 with a larger extension in y-direction as the extension LY. In this example, the additional area with extension LYO is destroyed by the milling of the cross-section surfaces 53.1 to 53.N. In a typical example, the extension LYO exceeds 20µm. The operation control unit 2 is configured to perform a 3D inspection inside an inspection volume 160 in a wafer 8. The operation control unit 2 is further configured to reconstruct the properties of semiconductor structures of interest from the 3D volume image. In an example, features and 3D positions of the semiconductor structures of interest, for example the positions of the HAR structures, are detected by the image processing methods, for example from HAR centroids. A 3D volume image generation including image processing methods and feature based alignment is further described in WO 2020 / 244795 A1.

Fig. 6 shows another example image of HAR structures, in this case a DRAM sample, captured with an angle perpendicular to the wafer surface. These structures include a plurality of columns, each column including a plurality of rings, as can be seen in Fig. 6.

For determining the measure of the distortion, as mentioned above (for example step 600 of Fig. 2) a series of images containing the same portion of a semiconductor device and including a plurality of objects may be taken. The images of Figures 5 and 6 are corresponding examples. In some embodiments, no milling is performed, such that the same image plane is captured repetitively. In other embodiments, milling may be performed before image capture and/or between capturing different images of the series, as long as the same objects (for example same columns) are included in the image. In some embodiments, the milling may remove surface charging from the sample, contamination from the sample or both.

As mentioned above, the sample, for example test wafer, may be a wafer dedicated for testing and determining the distortion, and may also be used for other purposes like defect analysis like defect analysis in some embodiments. Such other purposes will not be dealt with within the present application in detail. In some embodiments, the sample may only include part of a wafer, for example a diced wafer with semiconductor structures thereon, or may be a mask used for manufacturing semiconductor devices or part thereof.

Based on the series of images, then a measure of the distortion is obtained, basically based on changes of the positions, referred to as displacements, of objects between the images of the series of images. A series of images means at least two images, for

example three images or more, four images or more, five images or more etc. Fig. 7 is a flowchart illustrating determination of a measure of the distortion according to an embodiment. In other embodiments, some of the steps shown may be omitted, or may be replaced by alternative steps.

5

For the purpose of the description of Fig. 7, the plane of the images will be referred to as the x-y plane, and the z direction is perpendicular thereto.

10

In step 700, the images are aligned with each other, meaning that a translation is performed on the images such that, if it were a distortion free image capturing and the structures would be free of errors, corresponding objects would be at the same positions. In some embodiments, alignment markers as discussed above with respect to Fig. 5 may be used for alignment. In other embodiments, for example in case of a structure as in Fig. 6, the general structure of the image is known by design of the semiconductor devices, and the alignment may be based on this general structure. For example, in Fig. 6 the columns are arranged in a hexagonal manner, and the distances between the columns may be known by design. Also, WO 2021/180600 A1 mentioned above discusses approaches for image alignment. Generally, any method for image alignment known to the skilled person may be used.

20

25

At step 701, the coordinates of the objects are measured. For this, the objects are detected in the image. For object detection, any conventional method may be used. One approach known to the skilled person is the use of machine learning techniques, where for example in a plurality of images of corresponding semiconductor structures the objects are annotated and then provided to a machine learning logic like a neural network. For example, for identifying the columns in Fig. 6, images including such columns may be annotated, i.e. the columns may be marked. In other embodiments, the individual rings of the columns may be annotated, such that the individual rings are used as objects.

30

The object coordinates may be measured at any point of the object, as long as the point is the same for all images. For example, for the columns or rings of Fig. 6, the center of the columns or rings may be used as coordinates of the objects. In other embodiments, for other objects coordinates like the coordinates of a lower left corner, upper left corner etc. may be used. In another embodiment, in step 701 a cross-correlation based detection of the object and subsequent measuring of the coordinates can be obtained.

35

It should be noted that coordinates may be measured in pixels (picture elements) in the images, as long as all images have the same scale, or in “real life” units like nanometres. As the general size of the structures is known by the design from the structures, it is straightforward to convert one kind of measure (pixels) to the other (i.e. for example
5 nanometre) for example, this means, refer to Fig. 6, that for each of the columns shown the coordinate is determined in all images. In other embodiments, only some of the objects may be used, for example only some of the columns in Fig. 6 or some of the structures of Fig. 5, instead of using all objects.

10 In step 702, corresponding objects are identified in the images, i.e. the objects are “traced” to the stack of images. As a result of the identifying in step 702, a list of coordinates of each object in each image is obtained. Possible differences between the coordinates of the respective objects in different images are assumed to be caused by either a variable distortion of the images, i.e. a distortion which is not a translation
15 affecting the image as a whole, or inaccuracies in the determined object coordinates (like all measurements, the measuring of the object coordinates at 701 may have a certain measurement error). Due to the image alignment in step 700, any translation between the images as a whole or average translations of the images as a whole were eliminated and do not contribute to the differences.

20 In step 703, the differences between the coordinates of corresponding objects in image pairs is approximated by fitting a predefined transformation to the pairs of objects coordinates, for example an affine transformation or higher-order non-linear transformation. The fitting may be performed between any pairs of the images, e.g. for all
25 available pairs, between temporally adjacent images only (i.e. images taken immediately one after the other), or between any other selection of pairs of images. An affine translation, in this respect, is essentially a linear translation including offset, rotation, scaling, and shearing. In a fitting procedure, the transformation is applied to the objects coordinates in the first image to obtain the transformed object coordinates. The
30 parameters of the transformation (for example the elements of the affine transformation matrix) are varied to minimize the summed deviations of the transformed object coordinates from the respective object coordinates in the second image, to thus obtain a best-fit transformation.

35 In step 704, then a maximum displacement, for example in physical units like nanometres, caused by the best-fit transformations is calculated. For example, one applies the best-fit

transformation found in the previous step to the coordinates of all pixels in the first image and computes the maximum displacement of the transformed pixel coordinates with respect to their original coordinates. This maximum displacement may then be used as a measure for the distortion.

5

In other embodiments, in step 705 the maximum displacement may be normalized to the physical size of the image. Physical size of the image refers to the actual size of the semiconductor structure captured by the image, for example in micrometers.

- 10 Furthermore, also optionally, instead of taking the maximum displacements computed for all transformations between pairs of images as measure, i.e. a plurality of value, in step 706 the maximum displacements calculated for the different pairs may be combined to give a single value as the measure of the distortion. For example an average, median, maximum, minimum or a certain quantile of the computed maximum displacement over all
- 15 considered pairs of images may be used to characterize the distortion in the considered series of images.

- This figure of merit may then be used for performance evaluation by block 503 of Fig.3 or in step 603 of Fig. 2. In other embodiments, parameters of the charged particle beam
- 20 imaging device, for example device 500 of Fig. 1 or device 1000 of Fig. 3, as explained above with respect to block 502 of Fig. 1 or step 602 of Fig. 2. Examples for parameter setting will be described next referring to Figures 8 to 11.

- One example for parameter optimization is the optimization of the frame time of the
- 25 images, i.e. the time needed to acquire the image, the dwell time, i.e. the time needed to measure a single spot of the sample corresponding to one pixel of the image, and/or a frame resolution. The frame time corresponds to the dwell time times the number of pixels in the image plus an offset, such that these parameters are linked.

- 30 Fig. 8 is a diagram illustrating the displacement in nm/ μ m determined by the embodiment of Fig. 7, including step 705 and 706 (i.e. displacement in nm normalized to 1 μ m image size) as an average (mean) value of the maximum displacements calculated for the image pairs and as a median value. As can be seen, when the frame time exceeds about 30 seconds, a sharp increase of the displacement can be observed. This indicates that an
- 35 image drift is a main cause for the distortion.

Fig. 9 is a graph showing a measured error (standard deviation of critical dimension (CD) measurements of memory channels like the column structures in Fig. 6) . With such memory structures, the critical dimension is specifically used for the diameters of the memory channels/columns. As can be seen here, and as expected, the error of the measurement decreases with increased frame time because a larger frame time yields a higher signal to noise ratio in the image, which is a common effect for longer measurement times. Therefore, in this example the parameter setting at block 502 or Fig. 1 or step 602 of Fig. 2 may strive to find a balance between an acceptable distortion and a measurement accuracy. For example, thresholds may be given for distortion and desired accuracy, and based on these thresholds a frame time may be selected.

The tradeoff between measurement accuracy as shown in Fig. 9 and distortion as shown in Fig. 8 will be further illustrating referring to Figures 10 and 11. In Fig. 10, a curve 100 shows the signal noise, which is approximately inverse proportional to the signal to noise ratio over the dwell time for a single measurement spot, i.e. a single pixel. In order to reduce the signal noise, for example due to shot noise, the dwell time has to be above a certain threshold. For example, a line 801 shows a typical minimum dwell time for typical electron current levels in SEMs, which may be about 100 ns, which yields a typical level for CD noise, dCD , $>0,1$ nm. If a certain threshold noise level as for example indicated by a line 803 is desired, for example $dCD > 0.07$ nm, a corresponding higher minimum dwell time as indicated by line 804, for example >250 ns, is required. The threshold selected depends on the electron current and the secondary electrons / back-scattered electrons (SE/BSE) yield and therefore depends on material contrast and collection efficiency of SE/BSE. The former is given by the object, for example wafer or mask, the latter is limited by geometry, for example the working distance. Typical electron current levels in SEM devices are about 200 to 300 nA. Typical range for dwell times are 100 ns to 500 ns.

A higher dwell time in particular means a higher dose of charged particle, which increases the signal to noise ratio and correspondingly decreases the signal noise. In particular, the dose corresponds to the dwell time multiplied with the charged particle current.

Furthermore, Fig. 11 shows, in a curve 900, the distortion over frame time. As explained above, in order to reduce the distortion, i.e. the impact of vibrations on pattern distortion, the frame time has to be below a certain threshold. A line 901 shows a typical level for distortion caused by vibration, for example $DX < 2$ nm. In the example shown according to line 902 to a certain frame time. For a desired distortion level as indicated by a line 903,

as indicated by line 904 the frame time has to be lower. For example, for a distortion smaller than 1.5 nm a frame time <15 seconds may be required, corresponding to operating point 905. This corresponds to operating point 805.

5 The threshold required for the frame time may be tool-specific and environment-specific. For example, tools, i.e. charged particle beam imaging devices used for wafer or mask inspection) with a high precision control and/or having damping components to reduce vibrations may allow longer dwell times than tools in a noisy environment without such counter measures.

10

As already mentioned above, the frame time used for the x-axis in Fig. 11 and the dwell time of Fig. 10 are related via the number of pixels in the image. The frame time is the number of pixels x the dwell time + an offset for example from scanning flyback (e.g. jumping to the start of the line from the beginning of the last line in case of a linewise scanning) and other influences.

15

Thus, in some embodiments, based on the requirement of a maximum dwell time to achieve a low signal noise as shown in Fig. 10 and the requirement to have a low frame time below a threshold as explained with respect to Fig. 11, a maximum number of pixels per image and therefore a maximum image size, also referred to as frame size, may be determined. For example, from a requirement to a dCD accuracy below 0.07nm as explained above with respect to Fig. 10, a dwell time of 350ns minimum is derived. From a requirement of distortion $dx < 1.5\text{nm}$, a frame time below 15 seconds is determined. Assuming for example 10% offset time, a frame of approximately 38.5 MPixel can be acquired, for example a frame of about 6200 x 6200 Pixels. This pixel number may be calculated by dividing the required frame time by the dwell time + the offset, according to the formula given above.

20

25

30

Therefore, in embodiments, as a parameter based on the measure of the distortion, an image size in pixels may be determined.

As mentioned above, for example also the electron current level plays a role in determining the noise. If the electron current level is adjustable (or current level of ions in case of an ion beam device), this parameter may additionally be taken into account. Other parameters include the scanning path, sample mounting conditions, milling, imaging

35

angle, number of cross-section images, predetermined image quality comprising distortion, noise level etc..

5 The parameters may also depend on the samples. Parameters determined as above may be stored for various samples and then used later when characterizing the samples depending on the type of sample.

10 Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific embodiments shown and described without departing from the scope of the present invention. This application is intended to cover any adaptations or variations of the specific embodiments discussed herein. Therefore, it is intended that this invention be limited only by the claims and the
15 equivalents thereof.

20

CLAIMS

1. A method for determining a measure of an image distortion of a charged particle
5 beam imaging device (500; 1000), comprising:
providing a plurality of images of a region of a sample using the charged ion beam device
(500; 1000), and
determining the measure of the image distortion based on displacements of
corresponding objects between the plurality of images.
10
2. The method of claim 1, wherein determining the measure of the image distortion
based on the displacement comprises identifying corresponding objects in the plurality of
images, and measuring the coordinates of the objects in the images.
- 15 3. The method of claim 2, wherein the method comprises, prior to the identifying of
corresponding objects and measuring objects coordinates, aligning the plurality of images.
4. The method of claim 2 or 3, wherein, for determining the measure of the image
distortion based on the displacement, the method further includes fitting a transformation
20 to the coordinates of corresponding objects for pairs of images of the plurality of images,
and determining a maximum displacement value for each pair based on the fitted
functions.
5. The method of claim 4, wherein the pairs include temporally adjacent pairs.
25
6. The method of claim 5, wherein the method further comprises determining the
measure of the image distortion as a function of the maximum displacement values for the
different pairs.
- 30 7. The method of claim 6, wherein the function is selected from the group consisting
of a maximum determining function, in minimum determining function, an averaging
function, and a median function.
8. The method of any one of claims 1 to 7, furthermore comprising normalizing the
35 measure of the image distortion to a size of the portion of the sample captured by the
images.

9. The method of any one of claims 1 to 8, wherein the charged particle beam imaging device is a multi-beam scanning electron microscope.

5 10. A method of controlling a charged particle beam imaging device, comprising:
providing a measure of an image distortion of the charged particle beam imaging device,
and
setting at least one parameter of the charged particle beam imaging device based on the
measure of the image distortion.

10 11. The method of claim 10, wherein the measure of the image distortion is provided
with the method of any one of claims 1 to 9.

12. The method of claim 10 or 11, wherein the providing of the measure of the image
15 distortion is performed for a plurality of values of the at least one parameter, and wherein
the at least one parameter is set based on a threshold distortion.

13. The method of any one of claims 10 to 12, wherein the at least one parameter
comprises at least one of a frame rate, a dwell time, an image resolution, a beam current,
20 a sample mounting parameter, a milling parameter, and imaging angle of the charged
particle beam imaging device and a scanning parameter of the charged particle beam
imaging device.

14. The method of any one of claims 10 to 13, wherein setting the at least one
25 parameter is further based on a predefined signal to noise ratio threshold.

15. The method of claim 14, wherein the parameter comprises an image resolution,
wherein the image resolution is selected to satisfy both a threshold for the distortion and
the predefined signal to noise ratio threshold.

30 16. The method of any one of claims 1 to 15, wherein the plurality of images is
captured with the same focus setting.

17. A device, comprising:
35 a controller (501) configured to:

receive a plurality of images of a region of a sample using a charged ion beam device (500; 1000), and
determine a measure of an image distortion based on displacements of corresponding objects between the plurality of images.

5

18. A device comprising:
a controller (501) configured to:
provide a measure of an image distortion of a charged particle beam imaging device (500; 1000), and

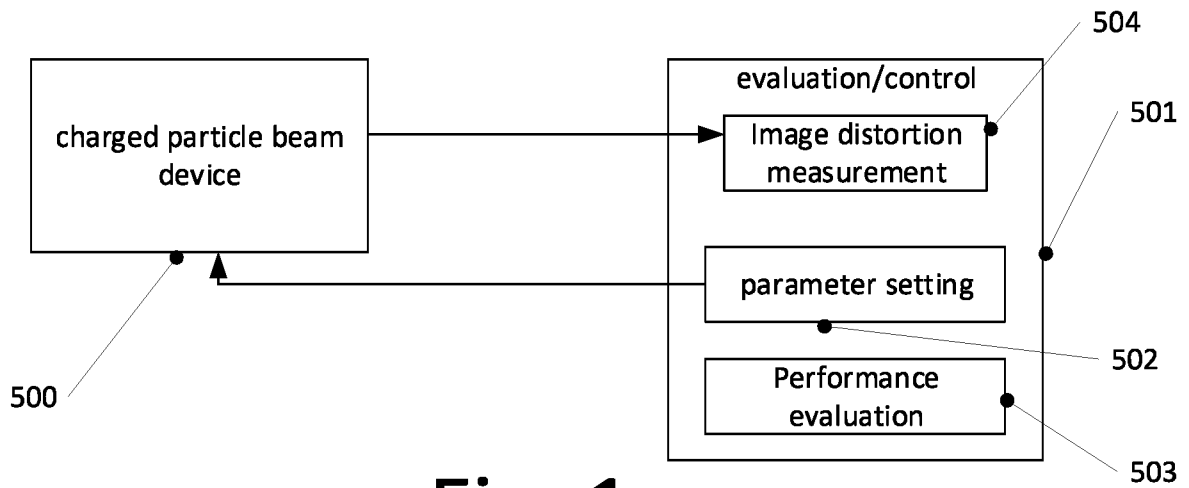
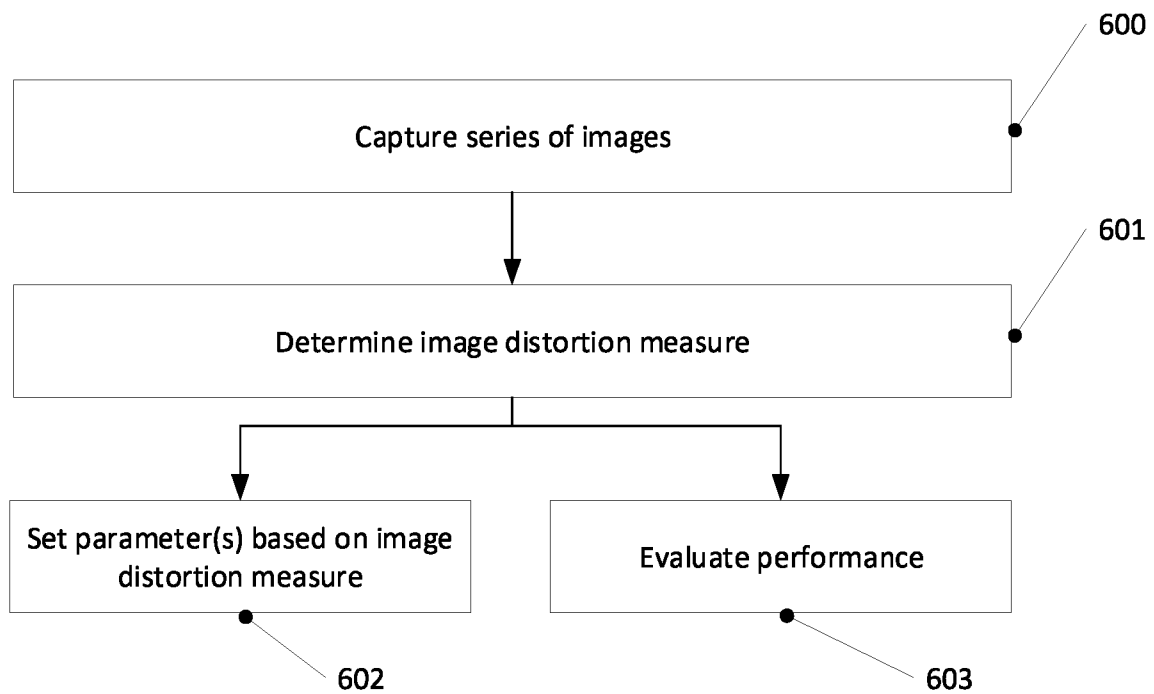
10 set at least one parameter of the charged particle beam imaging device (500; 1000) based on the measure of the image distortion.

19. The device of claim 17 or 18, wherein the device is configured to perform the method of any one of claims 1 to 16.

15

20. A system, comprising:
the device of any of claims 17 to 19, and
a charged particle beam imaging device (500; 1000).

20

**Fig. 1****Fig. 2**

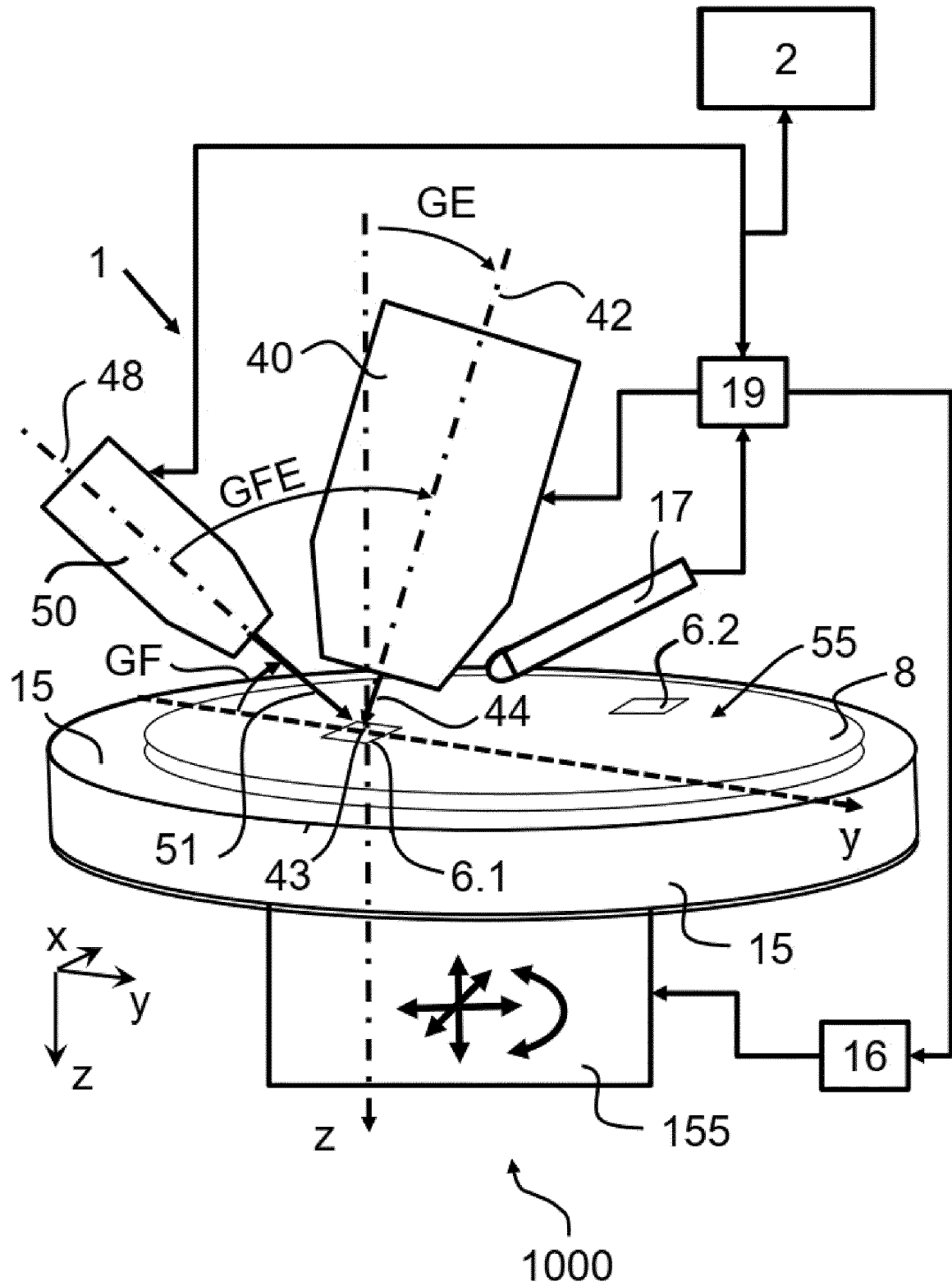


Fig. 3

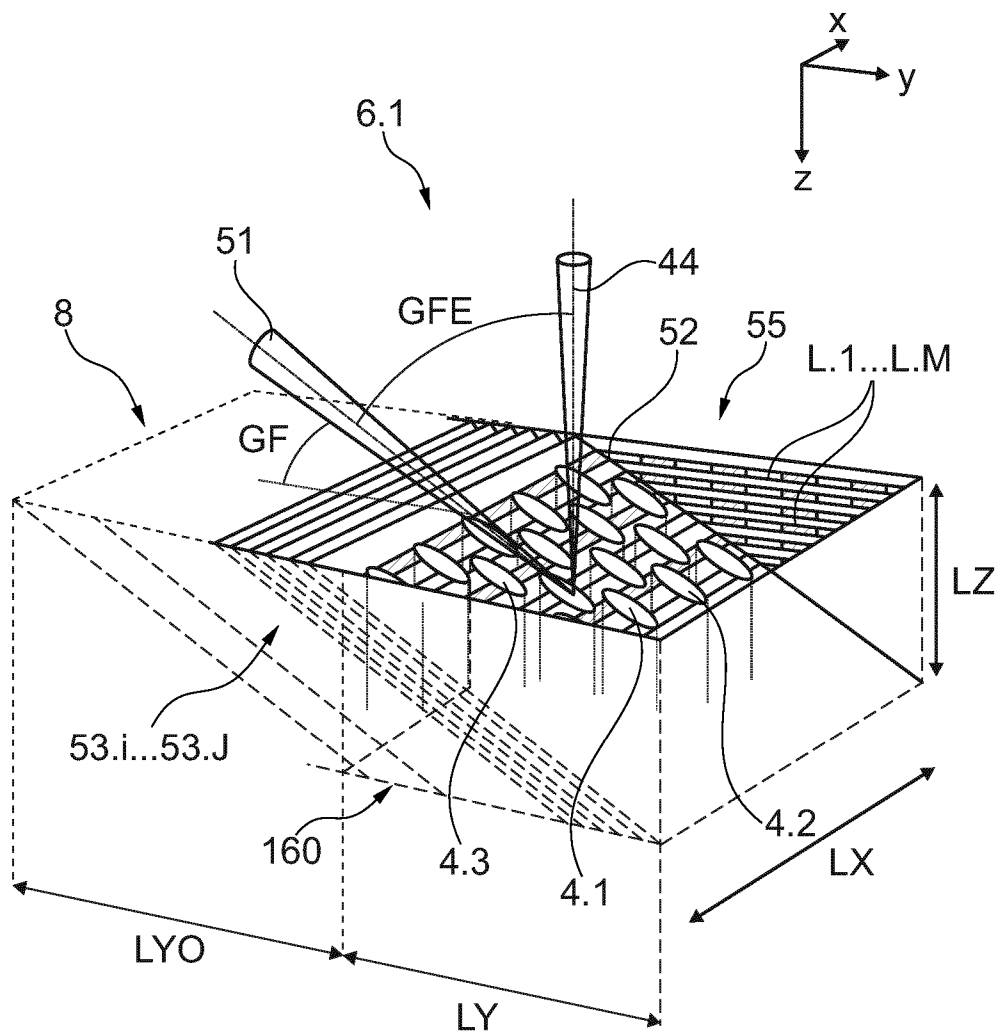


Fig. 4

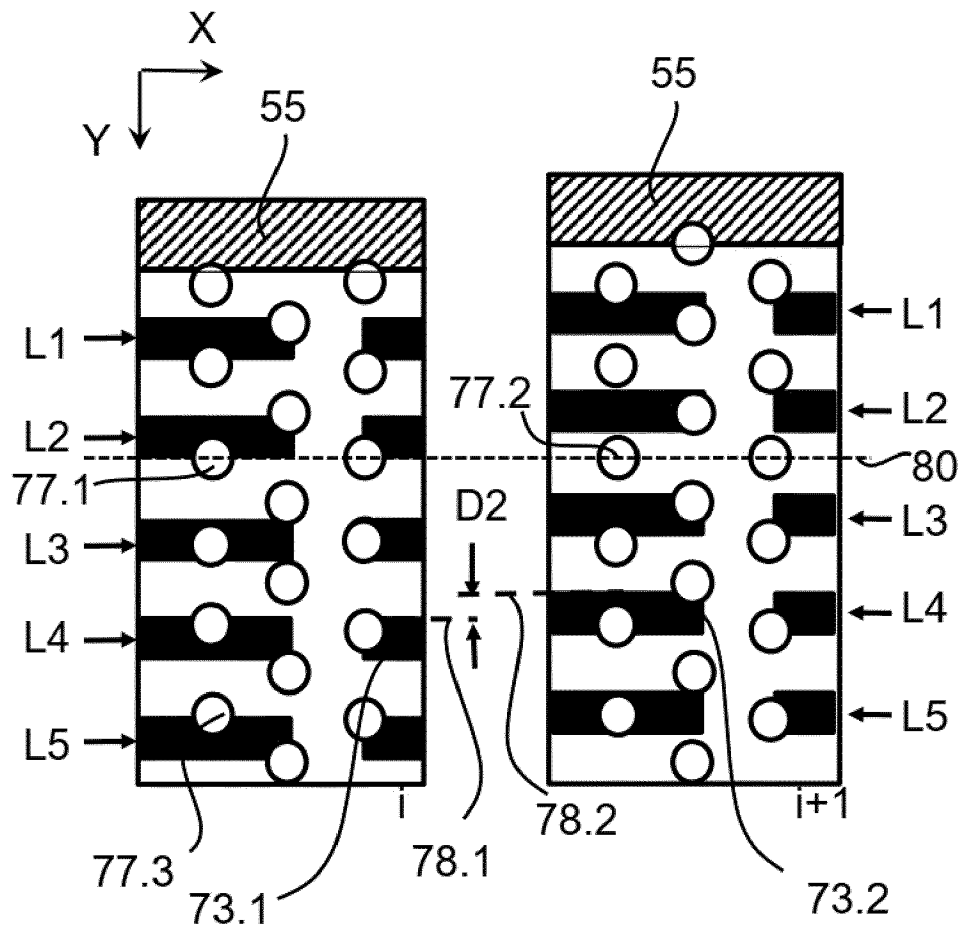


Fig. 5

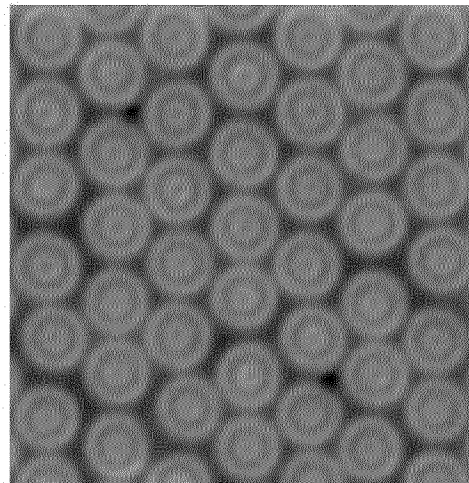
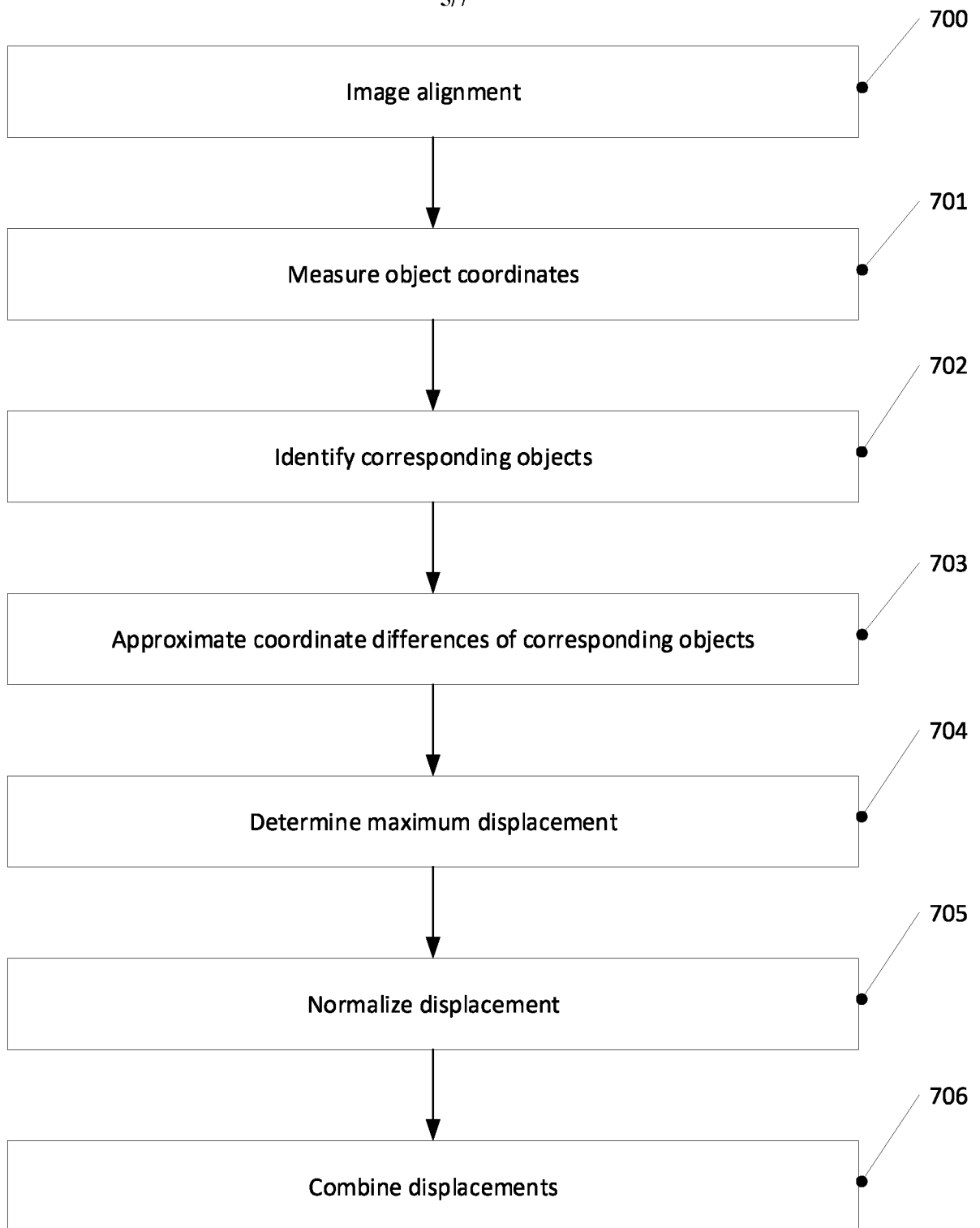


Fig. 6

**Fig. 7**

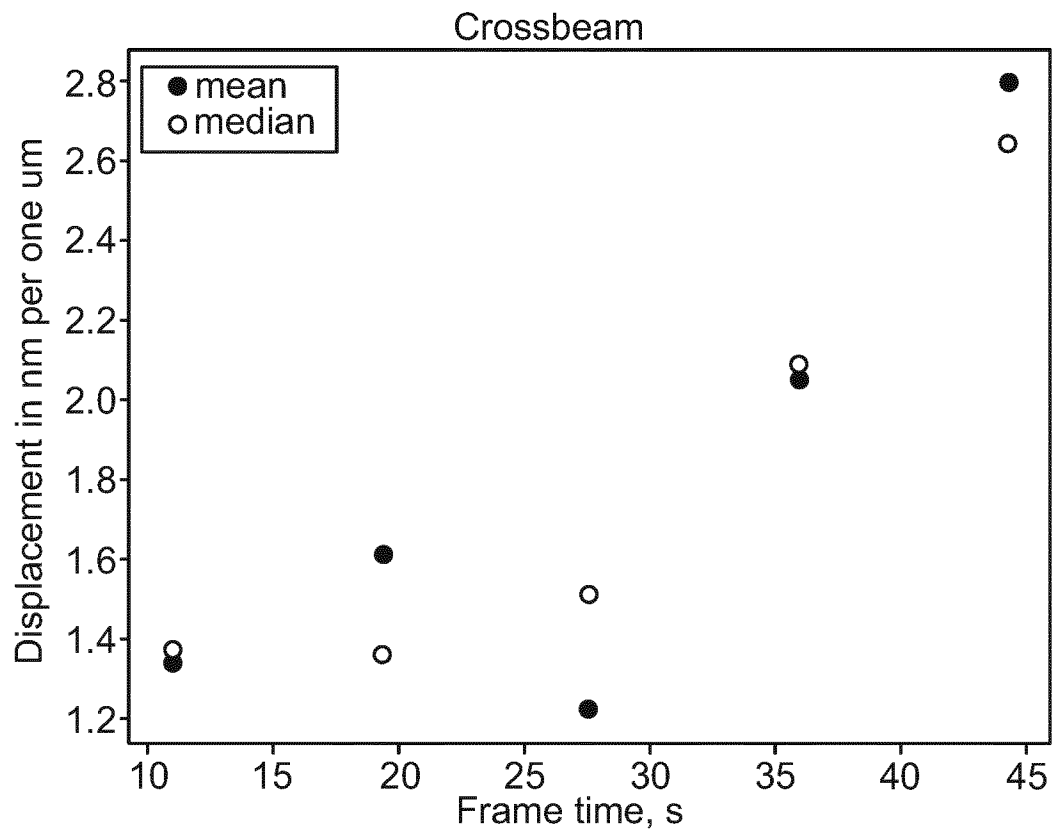


Fig. 8

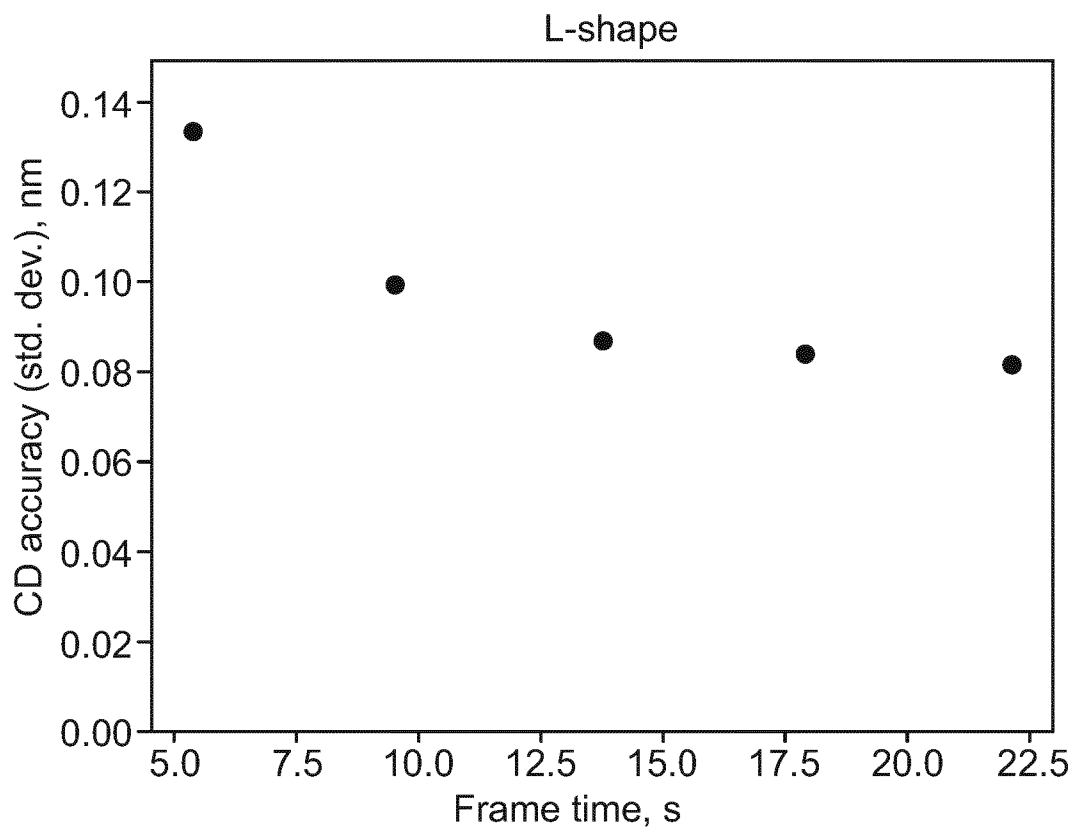


Fig. 9

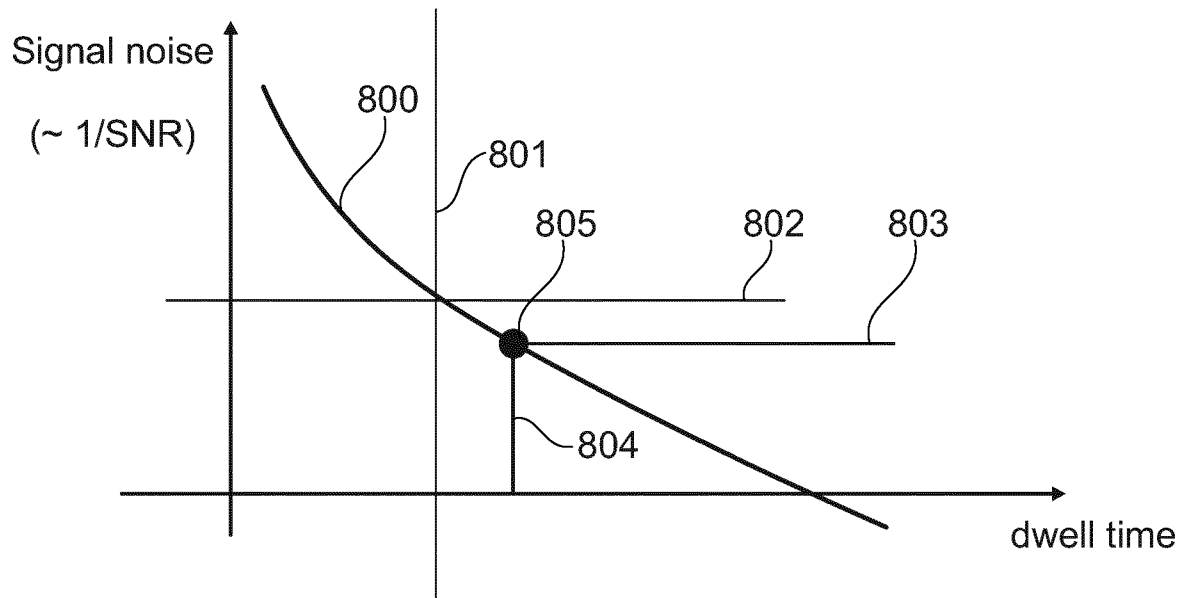


Fig. 10

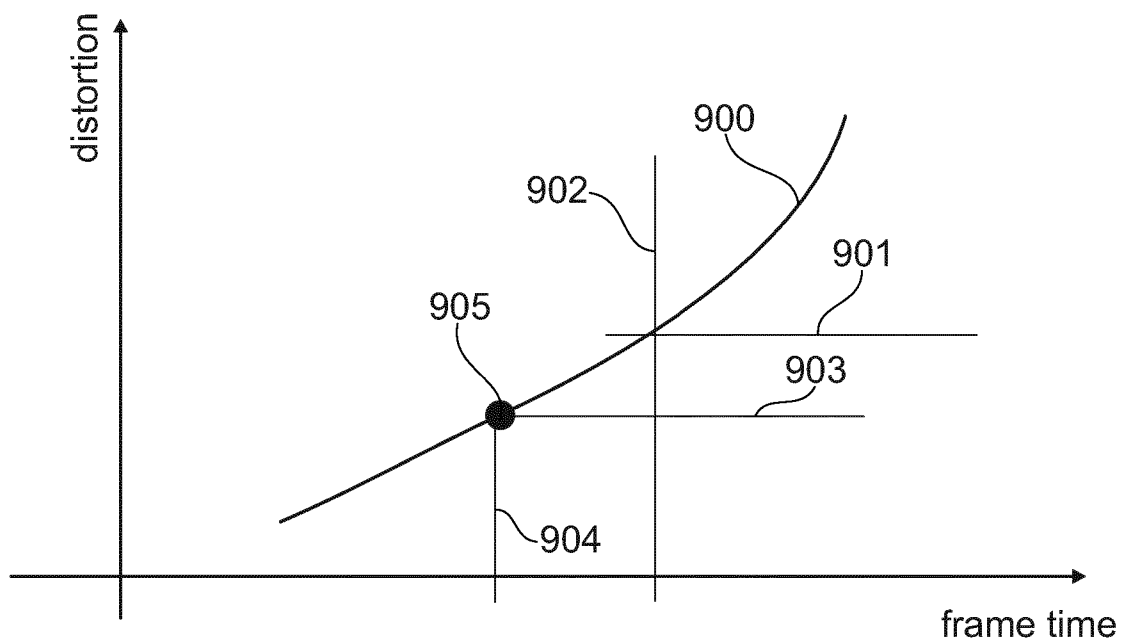


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/070638

A. CLASSIFICATION OF SUBJECT MATTER**INV. G06T7/00****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)

G06T

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PETR CIZMAR ET AL: "Real-Time Image Composition with Correction of Drift Distortion", INTERNET CITATION, 1 October 2009 (2009-10-01), pages 1-9, XP008161603, Retrieved from the Internet: URL: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=903741 [retrieved on 2013-04-22]	1-7, 17, 19, 20
A	abstract sections "Introduction", "Cross-Correlation with Noise Reduction", "Sub-Pixel-Accuracy Displacement Detection", "Composition Procedure" ----- --/--	8-16, 18



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

18 October 2023

Date of mailing of the international search report

06/11/2023

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

Eckert, Lars

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/070638

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GE HONGYU ET AL: "SEM-DCNet: A Self-Supervised Network for SEM Images Zonary Non-Linear Distortion Correction", 2022 2ND ASIA-PACIFIC CONFERENCE ON COMMUNICATIONS TECHNOLOGY AND COMPUTER SCIENCE (ACCTCS), IEEE, 25 February 2022 (2022-02-25), pages 117-121, XP034149816, DOI: 10.1109/ACCTCS53867.2022.00031 [retrieved on 2022-07-18]	1-3, 17, 19, 20
A	abstract sections "I. Introduction", "III.A. Zonary Distortion"	4-16, 18
E	----- WO 2023/147941 A1 (CARL ZEISS MULTISEM GMBH [DE]) 10 August 2023 (2023-08-10) page 1, lines 6-13 page 3, lines 4-12 page 5, lines 16-32 page 8, lines 10-14 page 11, line 26 - page 12, line 26 page 15, lines 1-4 page 16, line 36 - page 17, line 4 page 26, lines 3-4 -----	1-5, 8-11, 13-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/070638

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023147941	A1	10-08-2023	NONE