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(71) Applicant: ASML NETHERLANDS B.V. [NL/NL]; P.O. Box 324, 5500 AH Veldhoven (NL).

(72) Inventors: JANSEN, Frans; P.O. Box 324, 5500 AH Veldhoven (NL). GATTOBIGIO, Giovanni, Luca; P.O. Box 324, 5500 AH Veldhoven (NL).

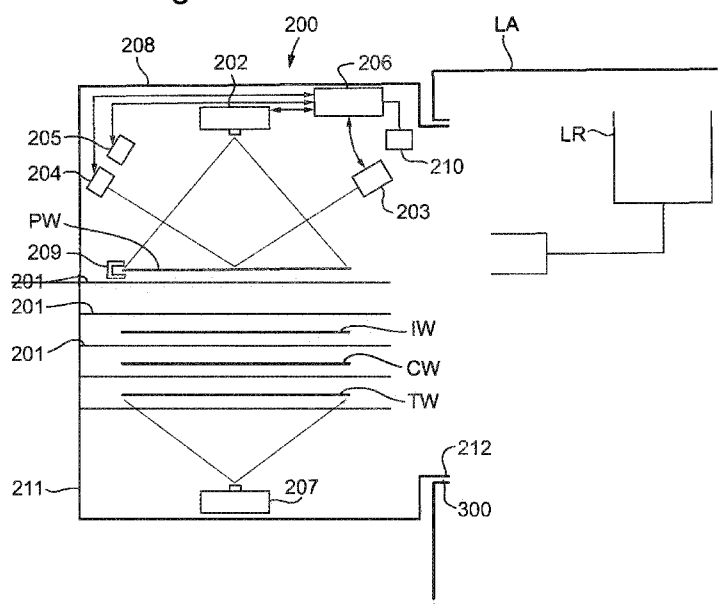
(74) Agent: VERHOEVEN, Johannes Theodorus Maria; P.O. Box 324, 5500 AH Veldhoven (NL).

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Fig. 4



(57) Abstract: The present invention relates to a substrate container (200) comprising a storage location (201) configured to store a substrate; a port (212) configured to connect the substrate container to a lithographic apparatus and to enable the substrate to be transferred to and from the lithographic apparatus; and a sensor system configured to detect a characteristic of the substrate stored in the storage location and to provide a sensor signal. The invention further relates to methods using such a substrate container.

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**A Substrate Container, a Lithographic Apparatus and
a Method using a Lithographic Apparatus**

CROSS-REFERENCE TO RELATED APPLICATIONS

5 **[0001]** This application claims priority of EP application 19163933.5 which was filed on 20th March 2019 and which is incorporated herein in its entirety by reference.

FIELD

10 **[0002]** The present invention relates to substrate containers and lithographic apparatus as well as methods using the substrate containers.

BACKGROUND

15 **[0003]** A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern (also often referred to as “design layout” or “design”) of a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate (e.g., a wafer).

20 **[0004]** As semiconductor manufacturing processes continue to advance, the dimensions of circuit elements have continually been reduced while the amount of functional elements, such as transistors, per device has been steadily increasing over decades, following a trend commonly referred to as “Moore’s law”. To keep up with Moore’s law the semiconductor industry is chasing technologies that enable to create increasingly smaller features. To project a pattern on a substrate a lithographic apparatus may use electromagnetic radiation. The wavelength of this radiation determines the minimum size of features which are patterned on the substrate. Typical wavelengths currently in use are 365 nm (i-line), 248 nm, 193 nm and 13.5 nm.

25 **[0005]** In an immersion lithographic apparatus an immersion liquid is interposed in a space between a projection system of the apparatus and a substrate. In this specification, reference will be made in the description to localized immersion in which the immersion liquid is confined, in use, to the space between the projection system and a surface facing the projection system. The facing surface is a surface of substrate or a surface of the supporting stage (or substrate table) that is co-planar with the substrate surface. (Please note that any reference in the following text to “surface of the substrate” also refers in addition or in the alternative to a surface of the substrate table, unless expressly stated otherwise; and vice versa.) A fluid handling structure present between the projection system and the stage is used to confine the immersion liquid to the immersion space. The space filled by liquid is smaller in plan than the top surface of the substrate and the space remains substantially stationary relative to the projection system while the substrate and substrate stage move underneath.

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[0006] A lithographic apparatus may process 100 or 150 substrates per hour or more, each containing 100 or more dies or fields. Usually only a sample of substrates and a sample of dies or fields per substrate are inspected after each process step so it may take several hours to detect that something has occurred to cause a loss of yield (a reduction in the proportion of devices correctly formed) and more
5 hours to identify the cause of yield loss. By that time, many hundreds of faulty wafers may have been produced and require rework and many wafers may have progressed so that rework is no longer possible and must be scrapped. If the yield loss occurs in a later layer of the substrate, many hours of production may be lost.

10 SUMMARY

[0007] It is desirable, for example, to provide improved means to detect changes in the state of a lithographic apparatus.

[0008] According to an aspect, there is provided a container for substrates, comprising:

a location configured to store a substrate;

15 a port configured to connect to a lithographic apparatus and to enable a substrate to be transferred to and from the lithographic apparatus; and

a sensor system configured to detect a characteristic of a substrate stored in the storage location and provide a sensor signal.

[0009] According to an aspect, there is provided a device manufacturing method using a
20 lithographic apparatus having a projection system to project an image onto a substrate held on a substrate holder, the method comprising:

connecting to the lithographic apparatus a transportable container having a location storing a substrate; a port configured to connect to the lithographic apparatus and to enable the substrate to be transferred to and from the lithographic apparatus; and a sensor system configured to measure a
25 parameter of the substrate stored in the storage location;

loading the substrate from the container to the lithographic apparatus;

performing an action on the substrate in the lithographic apparatus;

unloading the substrate from the lithographic apparatus to the container; and

using the sensor to perform a measurement on the substrate after the unloading thereby

30 generating a measurement result.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate
35 corresponding parts, and in which:

[0011] Figure 1 schematically depicts a lithographic apparatus;

[0012] Figure 2 schematically depicts an immersion liquid confinement structure for use in a lithographic projection apparatus;

[0013] Figure 3 is a side cross-sectional view that schematically depicts a further immersion confinement structure according to an embodiment;

5 [0014] Figure 4 depicts a container for substrates according to an embodiment of the invention;

[0015] Figure 5 depicts a control system of an embodiment of the invention; and

[0016] Figure 6 depicts a method according to an embodiment of the invention.

DETAILED DESCRIPTION

10 [0017] In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 436, 405, 365, 248, 193, 157 or 126 nm).

[0018] The term “reticle”, “mask” or “patterning device” as employed in this text may be broadly interpreted as referring to a generic patterning device that can be used to endow an incoming radiation
15 beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate. The term “light valve” can also be used in this context. Besides the classic mask (transmissive or reflective, binary, phase-shifting, hybrid, etc.), examples of other such patterning devices include a programmable mirror array and a programmable LCD array.

[0019] Figure 1 schematically depicts a lithographic apparatus. The lithographic apparatus includes
20 an illumination system (also referred to as illuminator) IL configured to condition a radiation beam B (e.g., UV radiation or DUV radiation), a mask support (e.g., a mask table) MT constructed to support a patterning device (e.g., a mask) MA and connected to a first positioner PM configured to accurately position the patterning device MA in accordance with certain parameters, a substrate support (e.g., a substrate table) 60 constructed to hold a substrate (e.g., a resist coated wafer) W and connected to a
25 second positioner PW configured to accurately position the substrate support 60 in accordance with certain parameters, and a projection system (e.g., a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g., comprising one or more dies) of the substrate W.

[0020] In operation, the illumination system IL receives the radiation beam B from a radiation source
30 SO, e.g. via a beam delivery system BD. The illumination system IL may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic, and/or other types of optical components, or any combination thereof, for directing, shaping, and/or controlling radiation. The illuminator IL may be used to condition the radiation beam B to have a desired spatial and angular intensity distribution in its cross section at a plane of the patterning device MA. The term
35 “projection system” PS used herein should be broadly interpreted as encompassing various types of projection system, including refractive, reflective, catadioptric, anamorphic, magnetic, electromagnetic

and/or electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, and/or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system” PS.

5 **[0021]** The lithographic apparatus is of a type wherein at least a portion of the substrate W may be covered by an immersion liquid having a relatively high refractive index, e.g., water, so as to fill an immersion space 10 between the projection system PS and the substrate W – which is also referred to as immersion lithography. More information on immersion techniques is given in US 6,952,253, which is incorporated herein by reference.

10 **[0022]** The lithographic apparatus may be of a type having two or more substrate supports 60 (also named “dual stage”). In such “multiple stage” machine, the substrate supports 60 may be used in parallel, and/or steps in preparation of a subsequent exposure of the substrate W may be carried out on the substrate W located on one of the substrate support 60 while another substrate W on the other substrate support 60 is being used for exposing a pattern on the other substrate W.

15 **[0023]** In addition to the substrate support 60, the lithographic apparatus may comprise a measurement stage (not depicted in Fig. 1). The measurement stage is arranged to hold a sensor and/or a cleaning device. The sensor may be arranged to measure a property of the projection system PS or a property of the radiation beam B. The measurement stage may hold multiple sensors. The cleaning device may be arranged to clean part of the lithographic apparatus, for example a part of the projection
20 system PS or a part of a system that provides the immersion liquid. The measurement stage may move beneath the projection system PS when the substrate support 60 is away from the projection system PS.

[0024] In operation, the radiation beam B is incident on the patterning device, e.g. mask, MA which is held on the mask support MT, and is patterned by the pattern (design layout) present on patterning device MA. Having traversed the mask MA, the radiation beam B passes through the projection
25 system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and a position measurement system IF, the substrate support 60 can be moved accurately, e.g., so as to position different target portions C in the path of the radiation beam B at a focused and aligned position. Similarly, the first positioner PM and possibly another position sensor (which is not explicitly depicted in Figure 1) may be used to accurately position the patterning device MA with
30 respect to the path of the radiation beam B. Patterning device MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks P1, P2 as illustrated occupy dedicated target portions, they may be located in spaces between target portions. Substrate alignment marks P1, P2 are known as scribe-lane alignment marks when these are located between the target portions C.

35 **[0025]** In this specification, a Cartesian coordinate system is used. The Cartesian coordinate system has three axis, i.e., an x-axis, a y-axis and a z-axis. Each of the three axis is orthogonal to the other two

axis. A rotation around the x-axis is referred to as an Rx-rotation. A rotation around the y-axis is referred to as an Ry-rotation. A rotation around about the z-axis is referred to as an Rz-rotation. The x-axis and the y-axis define a horizontal plane, whereas the z-axis is in a vertical direction. The Cartesian coordinate system is not limiting the invention and is used for clarification only. Instead,
5 another coordinate system, such as a cylindrical coordinate system, may be used to clarify the invention. The orientation of the Cartesian coordinate system may be different, for example, such that the z-axis has a component along the horizontal plane.

[0026] A controller 500 controls the overall operations of the lithographic apparatus and in particular performs an operation process described further below. Controller 500 can be embodied as a suitably-
10 programmed general purpose computer comprising a central processing unit, volatile and non-volatile storage means, one or more input and output devices such as a keyboard and screen, one or more network connections and one or more interfaces to the various parts of the lithographic apparatus. It will be appreciated that a one-to-one relationship between controlling computer and lithographic apparatus is not necessary. One computer can control multiple lithographic apparatuses. Multiple
15 networked computers can be used to control one lithographic apparatus. The controller 500 may also be configured to control one or more associated process devices and substrate handling devices in a lithocell or cluster of which the lithographic apparatus forms a part. The controller 500 can also be configured to be subordinate to a supervisory control system 600 of a lithocell or cluster and/or an overall control system of a fab.

[0027] Arrangements for providing liquid between a final lens element 100 of the projection system PS and the substrate W can be classed into three general categories. These are the bath type arrangement, the so-called localized immersion systems and the all-wet immersion systems. The present invention relates particularly to the localized immersion systems.

[0028] In an arrangement which has been proposed for a localized immersion system, a liquid
25 confinement structure 12 extends along at least a part of a boundary of an immersion space 10 between the final lens element 100 of the projection system PS and the facing surface of the stage or table facing the projection system PS. The facing surface of the table is referred to as such because the table is moved during use and is rarely stationary. Generally, the facing surface of the table refers to a surface of a substrate W, substrate table 60 which surrounds the substrate W or both.

[0029] Figures 2 and 3 show different features which may be present in variations of confinement structure 12. The features described herein may be selected individually or in combination as shown or as required.

[0030] Figure 2 shows two variants of a liquid confinement structure 12 around the bottom surface of a last lens element 100; the left hand side shows one variant and the right hand side another. Features
35 of the two variants may be combined in a single liquid confinement structure. The last lens element 100 has an inverted frustro-conical shape 30. The frustro-conical shape 30 having a planar bottom

surface and a conical surface. The frustro-conical shape 30 protrudes from a planar surface and having a bottom planar surface. The bottom planar surface is the optically active portion of the bottom surface of the last lens element, through which the projection beam may pass. The liquid confinement structure surrounds at least part of the frustro-conical shape 30. The liquid confinement structure 12 has an inner-
5 surface which faces towards the conical surface of the frustro-conical shape. The inner-surface and the conical surface have complementary shape. A top surface of the liquid confinement structure 12 is substantially planar. The liquid confinement structure 12 may fit around the frustro-conical shape of the last lens element 100. A bottom surface of the liquid confinement structure 12 is substantially planar and in use the bottom surface may be parallel with the facing surface of the substrate table 60 and/or
10 the substrate W. The distance between the bottom surface and the facing surface may be in the range of 30 to 500 micrometers, desirably in the range of 80 to 200 micrometers.

[0031] The liquid confinement structure 12 extends closer to the facing surface of the substrate W and the substrate table 60 than the last lens element 100. The immersion space 10 is therefore defined between the inner surface of the liquid confinement structure 12, the planar surface of the frustro-conical
15 portion and the facing surface. During use, the immersion space 10 is filled with liquid. The liquid fills at least part of a buffer space between the complementary surfaces between the last lens element 100 and the liquid confinement structure 12. In an embodiment, the liquid fills at least part of the immersion space 10 between the complementary inner-surface and the conical surface.

[0032] Liquid is supplied to the immersion space 10 through an opening formed in the surface of the liquid confinement structure 12. The liquid may be supplied through a supply opening 20 in the inner-
20 surface of the liquid confinement structure 12. Alternatively or additionally, the liquid is supplied from an under supply opening 23 formed in the undersurface of the liquid confinement structure 12. The under supply opening 23 may surround the path of the projection beam and it may be formed of a series of openings in an array. The liquid is supplied to fill the immersion space 10 so that flow through the
25 immersion space 10 under the projection system PS is laminar. The supply of liquid from the under supply opening 23 under the liquid confinement structure 12 additionally prevents the ingress of bubbles into the immersion space 10. This supply of liquid functions as a liquid seal.

[0033] The liquid may be recovered from a recovery opening 21 formed in the inner-surface. The recovery of the liquid through the recovery opening 21 may be by application of an under pressure; the
30 recovery through the recovery opening 21 as a consequence of the velocity of the liquid flow through the immersion space 10; or the recovery may be as a consequence of both. The recovery opening 21 may be located on the opposite side of the supply opening 20, when viewed in plan. Additionally or alternatively, the liquid may be recovered through an overflow opening 24 located on the top surface of the liquid confinement structure 12. Overflow opening 24 prevents the upper surface 22 of the
35 immersion liquid rising too high.

[0034] Additionally or alternatively, liquid may be recovered from under the liquid confinement structure 12 through a bottom recovery opening. The bottom recovery opening may serve to hold (or 'pin') a meniscus 33 to the liquid confinement structure 12. The meniscus 33 forms between the liquid confinement structure 12 and the facing surface and it serves as border between the liquid space and the gaseous external environment. The bottom recovery opening may be a porous member 25 or a porous plate which may recover the liquid in a single phase flow. The bottom recovery opening may be a series of pinning openings 32 through which the liquid is recovered. The pinning openings 32 may recover the liquid in a two phase flow.

[0035] Optionally radially outward, with respect to the inner-surface of the liquid confinement structure 12, is a gas knife opening 26. Gas may be supplied through the gas knife opening 26 at elevated speed to assist confinement of the immersion liquid in the immersion space 10. The supplied gas may be humidified and it may contain carbon dioxide. The supplied gas may consist essentially of carbon dioxide and water vapor. Radially outward of the gas knife opening 26 is a gas recovery opening 18 for recovering the gas supplied through the gas knife. Further openings, for example open to atmosphere or to a gas source, may be present in the bottom surface of the liquid confinement structure 12. For example, further openings may be present between the gas knife opening 26 and the gas recovery opening 18 and/or between pinning openings 32 and the gas knife opening 26.

[0036] Features shown in Figure 3 which are common to Figure 2 share the same reference numbers. The liquid confinement structure 12 has an inner surface which complements the conical surface of the frustro-conical shape. The undersurface of the liquid confinement structure 12 is closer to the facing surface than the bottom planar surface of the frustro-conical shape.

[0037] Liquid is supplied to the space through supply openings formed in the inner surface of the confinement structure. The supply openings 34 are located towards the bottom of the inner surface, perhaps below the bottom surface of the frustro-conical shape. The supply openings are located inner surface, space apart around the path of the projection beam.

[0038] Liquid is recovered from the immersion space 10 through recovery openings in the undersurface of the liquid confinement structure 12. As the facing surface moves under the liquid confinement structure 12, the meniscus 33 may migrate over the surface of the recovery opening in the same direction as the movement of the facing surface. The recovery openings may be formed of a porous member 25 or a porous plate. The liquid may be recovered in single phase. In an embodiment the liquid may be recovered in a two phase flow. The two phase flow is received in a chamber 35 within the liquid confinement structure 12 where it is separated into liquid and gas. The liquid and gas are recovered through separate channels 36, 38 from the chamber 35.

[0039] An inner periphery 39 of the undersurface of liquid confinement structure 12 extends into the immersion space 10 away from the inner surface to form a plate 40. The inner periphery 39 forms a small aperture which may be sized to match the shape and size of the projection beam. The plate 40

may serve to isolate liquid either side of it. The supplied liquid flows inwards towards the aperture, through the inner aperture and then under the plate 40 radially outwardly towards the surrounding recovery openings.

[0040] In an embodiment the liquid confinement structure 12 may be in two parts: an inner part 12a and an outer part 12b. For convenience this arrangement is shown in the right-hand part of Figure 3. The two parts may move relatively to each other, in a plane parallel to the facing surface. The inner part 12a may have the supply openings 34 and it may have the overflow recovery 24. The outer part 12b may have the plate 40 and the recovery opening. The inner part 12a may have an intermediate recovery 42 for recovering liquid which flows between the two parts.

[0041] Most lithographic apparatus have a port for connection to a Front Opening Unified Pod (commonly referred to as a FOUP). A FOUP is an enclosure for storing and transporting substrates in a controlled environment. When the FOUP is connected to the lithographic apparatus, substrates can be loaded into and unloaded from the lithographic apparatus without exposure to an external environment.

[0042] The present invention proposes to provide additional capabilities to a container for substrates, e.g. a FOUP, to enable monitoring of the performance and/or status of a lithographic apparatus. A FOUP provided with additional capabilities may be referred to herein as an enhanced FOUP.

[0043] In a first aspect of the invention, an enhanced FOUP has a sensing system configured to perform measurements on substrates in the enhanced FOUP. By performing measurements on a substrate, e.g. a production substrate, in an enhanced FOUP attached to the lithographic apparatus or other process tool it becomes possible to detect any issues that might cause a loss of yield more quickly than if the measurements are made in a remote metrology apparatus.

[0044] In a second aspect of the invention, the enhanced FOUP is provided with special substrates which can be used for measuring, inspecting or maintaining the lithographic apparatus. For example the special substrates may include an inspection substrate that includes one or more sensors such as a camera for inspecting a component of the lithographic apparatus. Another type of special substrate may be a cleaning substrate which can be used to remove contaminants from the lithographic apparatus. Yet a further type of special substrate may be a witness substrate which is arranged to be affected in a detectable way by some parameter or characteristic of the lithographic apparatus. An example is a transparent substrate which might collect a contaminant when processed in the lithographic apparatus; the contaminant is more easily visible on the transparent substrate than it would be on a conventional opaque substrate. Other types of special substrates are possible. Special substrates are arranged to have dimensions similar enough to production substrates that they can be accepted by the lithographic apparatus without modification thereto.

[0045] A third aspect of the invention is a method of monitoring the performance of the lithographic apparatus by measuring production substrates and/or special substrates that have been processed by the

lithographic apparatus. Substrates may be measured before as well as after the processing. In a diagnostic mode, a substrate may be measured after only some steps of a normal exposure process have been carried out in order to identify which step of a process is causing problems.

[0046] It will be appreciated that the different aspects of the invention may be combined. In all aspects of the invention, the enhanced FOUP may comply with relevant parts of SEMI standards, e.g. SEMI E47.1106, SEMI E62-1106 SEMI E158-0134 and SEMI E162-0912. so that it can be used with a lithographic apparatus having a standard FOUP port without modification. These standards are hereby incorporated herein by reference in their entirety. Accordingly the present invention can provide enhanced capabilities to existing lithographic apparatus.

[0047] An enhanced FOUP 200 according to an embodiment of the invention is depicted schematically in Figure 4. Enhanced FOUP 200 has a plurality of storage locations 201 each configured to store a substrate of standard size, e.g. 200 mm, 300 mm or 450 mm. The storage locations may comprise ledges on which the edges of the substrates rest and/or clamping devices to hold the substrates in place. A standard FOUP may have space for 25 substrates for example. An enhanced FOUP might have fewer spaces because some volume is taken up by active components as described below.

[0048] Enhanced FOUP 200 has a port 212 on a side surface (i.e. a surface that is perpendicular to substrates stored in the FOUP) that has standard shape and dimensions so as to be engageable with a complementary part 300 on a lithographic apparatus or other tool. The port enables substrates to be transferred into and out of the lithographic apparatus or other tool by loading robot LR.

[0049] Enhanced FOUP 200 has a sensor system for making measurements of substrates contained therein. The sensor system can include a variety of sensors and other components, a variety of which are depicted in Figure 4 and described below by way of example.

[0050] Camera 202 is arranged to image the upper surface (i.e. the surface on which exposures are performed) of a substrate, e.g. a production substrate PW, held in the enhanced FOUP 200. Camera 202 may be configured to image the whole of a substrate or just part thereof, e.g. the edges. Multiple cameras may be provided to enable imaging of the whole substrate if the field of view of one camera is not large enough to cover the whole of a substrate. Desirably, camera 202 is capable of detecting contaminants as small as few μm up to $\sim 200 \mu\text{m}$. It should be noted that in some circumstances it is not necessary for the camera to be able to resolve a contaminant in order to be able to detect it. For example, the presence of contaminants smaller than the equivalent size of a pixel may be inferred from intensity or color differences between pixels. Camera 202 is not intended to directly detect manufacturing flaws in a production substrate but to detect indicators that might suggest a condition or event that is likely to lead to yield loss. For example, in an immersion lithographic apparatus the camera 202 might detect waterloss left on the top of the resist, or an increase thereof, that indicates a problem with a liquid confinement system. Contaminants, for example fibers, can also be detected by cameras 202.

[0051] Illuminator 203 (a light source) is provided to illuminate the substrate for imaging. Desirably, the illuminator 203 provides oblique illumination so as to highlight contaminants. The wavelength of light output by illuminator 203 can be chosen to maximize contrast of expected contaminants. If the wavelength is controllable, e.g. by selectively energizing different sources within the illuminator, then
5 images under different colored illumination can be taken to assist in identifying different contaminants. The wavelength of light output by illuminator 203 may range from infra-red to ultraviolet.

[0052] Illuminator 203 can also be used with simple light intensity detectors to detect contaminants. A first light intensity detector 204 is arranged to detect light specularly reflected from the substrate and a second light intensity detector 204 is arranged to detect light scattered from the substrate. An increase
10 in the intensity of scattered light and a decrease in intensity of specularly reflected light is indicative of the presence of contamination on the substrate.

[0053] A second camera 207 (or a plurality of second cameras 207) can be provided to image a substrate, e.g. transparent substrate TW, from below. Imaging the lower surface of a substrate enables detecting of contaminants, e.g. particles, which might adhere to the lower surface of the substrate, e.g.
15 originating from the substrate holder. Imaging the lower surface of the substrate may also enable detection of damage caused by substrate handling components such as e-pins or substrate handling robots. If a transparent substrate is used as a witness substrate, contaminants on both top and bottom surfaces can be detected simultaneously.

[0054] A dimension sensor 209, e.g. a laser caliper, is provided to measure a dimension of a substrate.
20 Damage to an edge of a substrate that is detectable by the dimension sensor may indicate a problem with the lithographic apparatus or another tool in the track.

[0055] An environmental sensor 210 can be provided to sense a parameter or characteristic of the environment of the enhanced FOUP. Environmental sensor 210 may be a temperature sensor, a humidity sensor or a chemical sensor, for example. A chemical sensor may be configured to detect
25 specific compounds, e.g. volatile organic compounds outgassed by a photo-sensitive layer on a substrate. An abnormal measurement by the environmental sensor may be indicative of an error in the lithographic apparatus. Measurements by the environmental sensor may provide context for measurements by other sensors.

[0056] Enhanced FOUP 200 may be provided with a controller 206, which is depicted schematically
30 in more detail in Figure 6. Controller 206 may comprise a sensor-interface 2061, a central processing unit (CPU) 2062, memory (e.g. RAM) 2063, a network interface 2064 and a graphic processing unit (GPU) 2065.

[0057] Sensor interface 2061 is configured to connect to the various sensors forming the sensor system, such as cameras 202, 207, etc., and to pass data and control signals. Sensor interface 2061 may
35 connect to the sensors via wires, optical fibers or wirelessly, e.g. using a communication protocol such as Bluetooth™. Sensor interface 2061 may also be configured to communicate with inspection

substrates IW which may include sensors, such as cameras or pressure sensors, for inspecting a component of the lithographic apparatus, for example a liquid confinement system. Further details of inspection substrates that can be used with embodiments of the invention are disclosed in WO 2018/077517, WO 2017/008993, WO 2017/08931, WO 2018/007119, WO 2018/007118 and Research Disclosure RD652040, which documents are hereby incorporated by reference.

[0058] CPU 2062 is configured to execute programs stored in memory 2063 and to store data, such as measurement results, into memory 2063. Programs stored in memory 2063 may perform analysis of the measurement results or simply control the process of taking measurements with the analysis being performed elsewhere. Where analysis is performed by the controller 206 and involves analysis of images, GPU 2065 may be employed to speed up the processing of images.

[0059] Network interface 2064 communicates with external systems, e.g. a controller 500 of the lithographic apparatus or a supervisory control system 600 of the lithocluster or fab. Network interface 2064 may communicate via a wired connection or a wireless protocol such as WiFi™.

[0060] Analysis of images to detect contamination, whether performed in the enhanced FOUP or externally, may make use of a variety of techniques. In some cases, contaminants or other indicators of issues in the lithographic apparatus may be detected simply by comparing images of a substrate before and after a process step has been carried out or by comparing substrate images to reference images. In other cases more complex techniques, e.g. using machine learning, may be employed.

[0061] Enhanced FOUP 200 has a casing 211 to protect the substrates and other components. Casing 211 is desirably opaque so that internal optical sensors are not affected by changes in ambient lighting conditions. Casing 211 desirably has a non-reflective internal surface to minimize scattering of light from light source 203.

[0062] An exemplary method according to an embodiment of the invention is depicted schematically in Figure 6. First a substrate is loaded S1 into the enhanced FOUP and inspected S2 using appropriate sensors within the enhanced FOUP as described above. The substrate may be a production substrate, i.e. a substrate to be exposed to form devices thereon, or a special substrate as described above. The substrate is then loaded into the lithographic apparatus and exposed S3 to form a latent image thereon. The substrate is then transferred to the enhanced FOUP and inspected again S4. After this second inspection, the substrate is transferred to a process tool in the track and a pattern transfer step S5, such as etching or implantation, is carried out. Then the substrate is transferred to an enhanced FOUP and inspected a third time S6. It should be noted that the different inspection steps need not be carried out in the same enhanced FOUP. For example an enhanced FOUP may be mounted to a process tool rather than a lithography apparatus.

[0063] The results of the inspections S2, S4 and S6 are analyzed S7. The analysis S7 may be carried out separately on individual results or using multiple results from the same or different substrates. The analysis may be carried out in the enhanced FOUP(s) or in other computer systems.

[0064] In the event that analysis S7 of the inspection results indicates an issue, remedial action S8 is performed. Remedial action can take any of a number of different forms. For example the inspected substrates and/or substrates from the same or similar batches may be reworked. A change may be made to a subsequent process step to compensate for the detected issue. A correction to a process step applied to subsequent batches of substrates may be made. The lithographic apparatus or a process tool may be recalibrated. A maintenance action, e.g. a cleaning action, may be performed in the lithographic apparatus or a process tool. Combinations of some or all of these actions may be performed.

[0065] The method of Figure 6 is an example of monitoring a manufacturing process to detect problems. The invention can also be used to assist in diagnosis of problems, e.g. yield loss, for example, to determine which of the many sub-steps performed on a substrate when exposed in a lithographic apparatus is the cause of a problem. In the diagnostic mode, a substrate is inspected in the enhanced FOUP, loaded into the lithographic apparatus, subjected to a limited number of sub-steps, unloaded and inspected again. The process is repeated with a different set of sub-steps being performed. For example, in the first iteration the substrate may be loaded and qualified only. In the second iteration the substrate may be loaded, qualified, transferred to the exposure station (in a dual stage apparatus) and exposed to immersion liquid. Comparison of the inspection results may assist in identifying which sub-step is the cause of contamination.

[0066] A lithographic apparatus or a process tool may have a load lock to allow substrates to be directly transferred between the lithographic apparatus and the process tool. In such a case, ports for the attachment of FOUPs may be used only rarely. Therefore an enhanced FOUP according to the invention may be permanently or semi-permanently attached to a FOUP port of a lithographic apparatus or process tool without significantly affecting the normal operation of the fab.

[0067] If the invention is to be used in a fab where FOUPs are routinely used to transport wafers between tools, the enhanced FOUP is desirably compatible with the FOUP handling apparatus or manual handling protocols in use.

[0068] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “wafer” or “die” herein may be considered as synonymous with the more general terms “substrate” or “target portion”, respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that

the term substrate used herein may also refer to a substrate that already contains one or multiple processed layers.

[0069] Although specific reference may have been made above to the use of embodiments of the invention in the context of optical lithography, it will be appreciated that the invention may be used in
5 other applications.

[0070] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described.

[0071] 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 invention as described without departing
10 from the scope of the claims set out below.

[0072] Clauses:

[0073] 1. A container for substrates, comprising a location configured to store a substrate and a port configured to connect to a lithographic apparatus and to enable a substrate to be transferred to and from the lithographic apparatus and a sensor system configured to detect a characteristic of a substrate stored
15 in the storage location and provide a sensor signal.

[0074] 2. A container according to clause 1 wherein the sensor system comprises a camera.

[0075] 3. A container according to clause 2 wherein the camera is configured to image one of the upper and lower surfaces of the substrate.

[0076] 4. A container according to clause 2 or 3 wherein the camera is capable of detecting a
20 contaminant having a dimension of 1 μm or more on a surface of the substrate.

[0077] 5. A container according to any one of the preceding clauses further comprising a light source configured to direct light to a surface of the substrate.

[0078] 6. A container according to clause 5 wherein the sensor system comprises a light sensor configured to detect light scattered from a contaminant on a surface of the substrate.

25 [0079] 7. A container according to any one of the preceding clauses wherein the sensor system comprises an environmental sensor, the environmental sensor being configured to sense at least one of temperature, humidity and the presence of one or more predetermined chemical compounds.

[0080] 8. A container according to any one of the preceding clauses wherein the sensor system is configured to measure a physical dimension of the substrate.

30 [0081] 9. A container according to any one of the preceding clauses further comprising a processor and a memory, the memory storing a program comprising code means that instructs the processor to analyse the sensor signal.

[0082] 10. A container according to any one of the preceding clauses further comprising an interface configured to communicate with an external data processing system, e.g. in the lithographic apparatus
35 or the fab.

[0083] 11. A container according to clause 10 further comprising an outer casing enclosing the

location and the sensor system, wherein the outer casing is opaque and/or has a non-reflective internal surface.

[0084] 12. A container according to any one of the preceding clauses further comprising a substrate interface configured to communicate with an electronic device of the substrate.

5 **[0085]** 13. A container according to any one of the preceding clauses wherein the port is located on a side of the container that is substantially perpendicular to the substrate when stored in the location.

[0086] 14. A container according to any one of the preceding clauses wherein the port complies with at least one of SEMI standards: SEMI E47.1106, SEMI E62-1106 SEMI E158-0134 and SEMI E162-0912.

10 **[0087]** 15. A device manufacturing method using a lithographic apparatus having a projection system to project an image onto a substrate held on a substrate holder, the method comprising connecting to the lithographic apparatus a transportable container having a location storing a substrate; a port configured to connect to the lithographic apparatus and to enable the substrate to be transferred to and from the lithographic apparatus; and a sensor system configured to measure a parameter of the substrate
15 stored in the storage location; loading the substrate from the container to the lithographic apparatus; performing an action on the substrate in the lithographic apparatus; unloading the substrate from the lithographic apparatus to the container; and using the sensor to perform a measurement on the substrate after the unloading thereby generating a measurement result.

[0088] 16. A method according to clause 15 wherein the substrate is one of a production substrate, a witness substrate, a cleaning substrate, a transparent substrate and an inspection substrate.
20

[0089] 17. A method according to clause 15 or 16 wherein the action includes at least one of: clamping the substrate to a substrate holder; performing a measurement on the substrate in the lithographic apparatus; confining an immersion liquid to a space in contact with the substrate; exposing the substrate using a projection beam of radiation; and unloading the substrate from the substrate holder.

25 **[0090]** 18. A method according to clause 15, 16 or 17 further comprising repeating the steps of loading, performing an action, unloading and using the sensor, wherein in the repeated step of performing an action, a different action or set of actions is performed.

[0091] 19. A method according to any one of clauses 15 to 18 further comprising an initial measurement step performed on the substrate using the sensor before the step of loading thereby to
30 generate an initial measurement result.

[0092] 20. A method according to any one of clauses 15 to 19 further comprising analysing the measurement result and performing a remedial action, wherein the remedial action comprises one or more of: reworking one or more production substrates; modifying a process recipe; calibrating the lithographic apparatus; and performing a maintenance action on the lithographic apparatus.

CLAIMS:

1. A container for substrates, comprising:
a storage location configured to store a substrate;
5 a port configured to connect to a lithographic apparatus and to enable the substrate to be transferred to and from the lithographic apparatus; and
a sensor system configured to detect a characteristic of the substrate stored in the storage location and provide a sensor signal.
- 10 2. A container according to claim 1 wherein the sensor system comprises a camera.
3. A container according to claim 2 wherein the camera is configured to image one of the upper and lower surfaces of the substrate.
- 15 4. A container according to claim 3 wherein the camera is capable of detecting a contaminant having a dimension of 1 μm or more on a surface of the substrate.
5. A container according to claim 1 or 3 further comprising a light source configured to direct light to a surface of the substrate.
- 20 6. A container according to claim 5 wherein the sensor system comprises a light sensor configured to detect light scattered from a contaminant on a surface of the substrate.
7. A container according to claim 1 wherein the sensor system comprises an environmental
25 sensor, the environmental sensor being configured to sense at least one of temperature, humidity and the presence of one or more predetermined chemical compounds.
8. A container according to claim 1 wherein the sensor system is configured to measure a
30 physical dimension of the substrate.
9. A container according to claim 1 further comprising an interface configured to communicate the sensor signal with an external data processing system.
10. A device manufacturing method using a lithographic apparatus having a projection system
35 to project an image onto a substrate held on a substrate holder,
the method comprising:

connecting to the lithographic apparatus a container for substrates having a storage location for storing the substrate; a port configured for connecting to the lithographic apparatus and to enable the substrate to be transferred to and from the lithographic apparatus; and a sensor system configured to measure a parameter of the substrate stored in the storage location;

- 5 loading the substrate from the container to the lithographic apparatus;
 projecting the image onto the substrate in the lithographic apparatus;
 unloading the substrate from the lithographic apparatus to the container; and
 using the sensor to perform a measurement on the substrate after the unloading thereby
generating a measurement result.

10

11. A method according to claim 10 wherein the substrate is one of a production substrate, a witness substrate, a cleaning substrate, a transparent substrate and an inspection substrate.

12. A method according to claim 10 further comprising an initial measurement step performed on
15 the substrate using the sensor before the step of loading the substrate from the container to the
lithographic apparatus thereby to generate an initial measurement result.

13. A method according to claim 10 further comprising analysing the measurement result and
performing a remedial action based on the analysis of the measurement result.

20

14. A method according to claim 12 further comprising analysing the measurement result and the
initial measurement result and performing a remedial action based on the analysis of the measurement
result and the initial measurement result.

- 25 15. A method according to claim 13 or 14 wherein the remedial action comprises one or more of:
reworking one or more production substrates; modifying a process recipe; calibrating the lithographic
apparatus; and performing a maintenance action on the lithographic apparatus.

Fig. 1

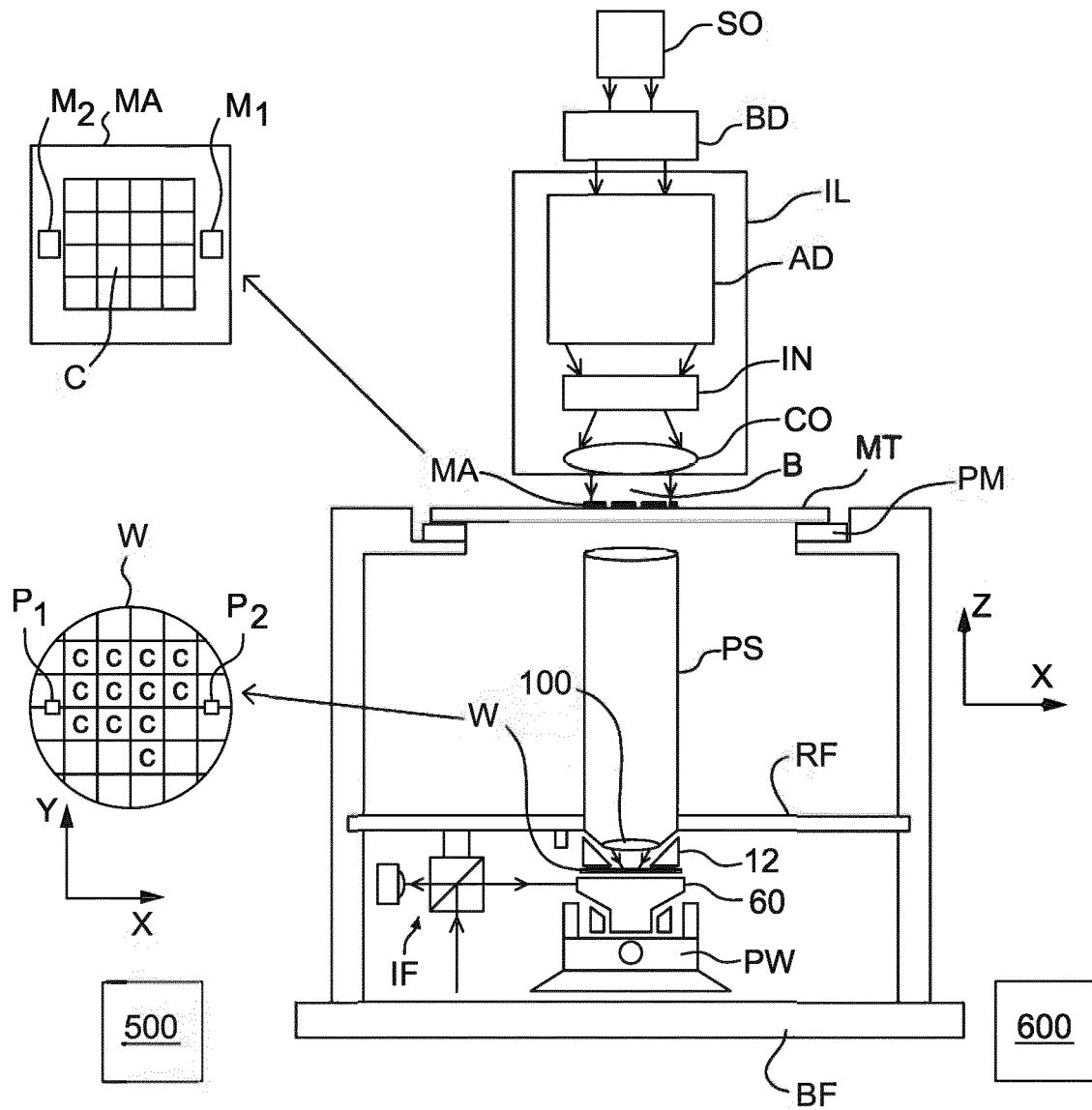


Fig. 2

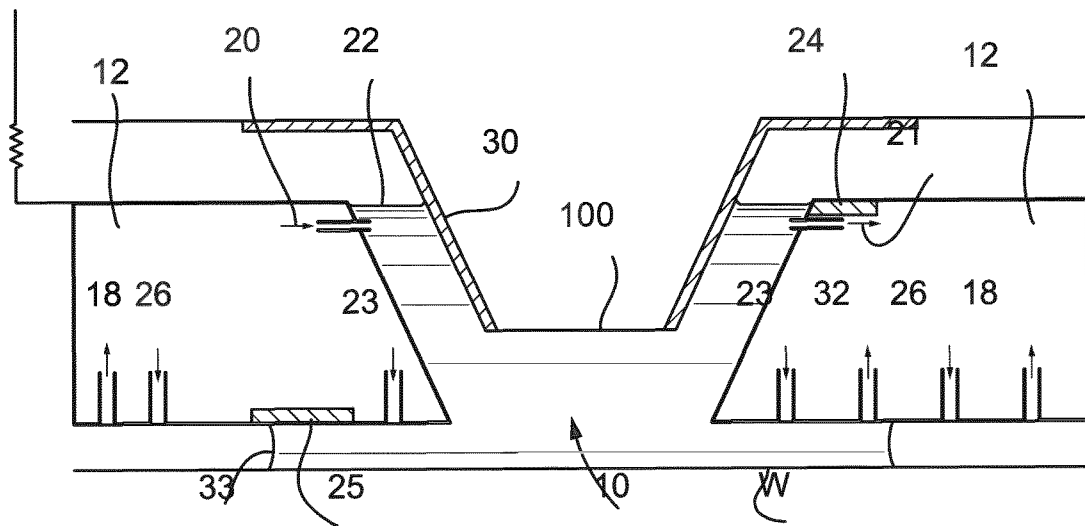


Fig. 3

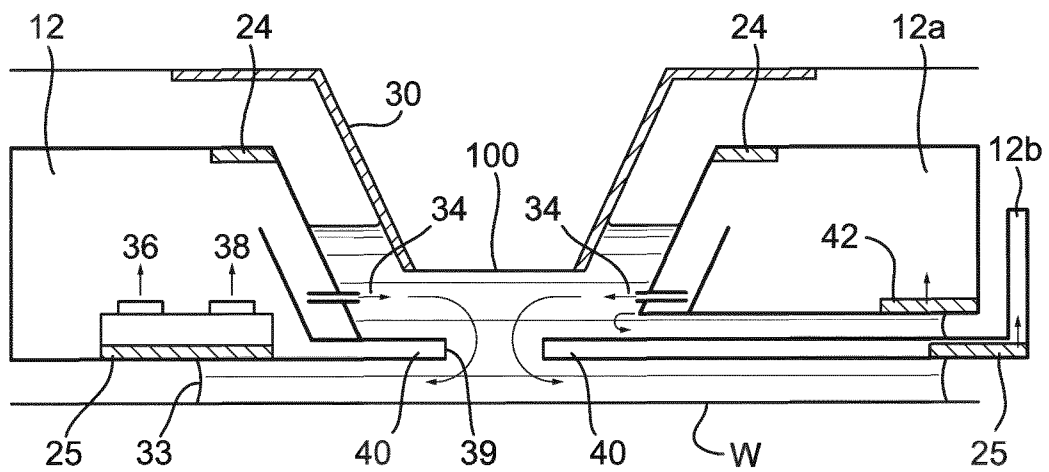


Fig. 4

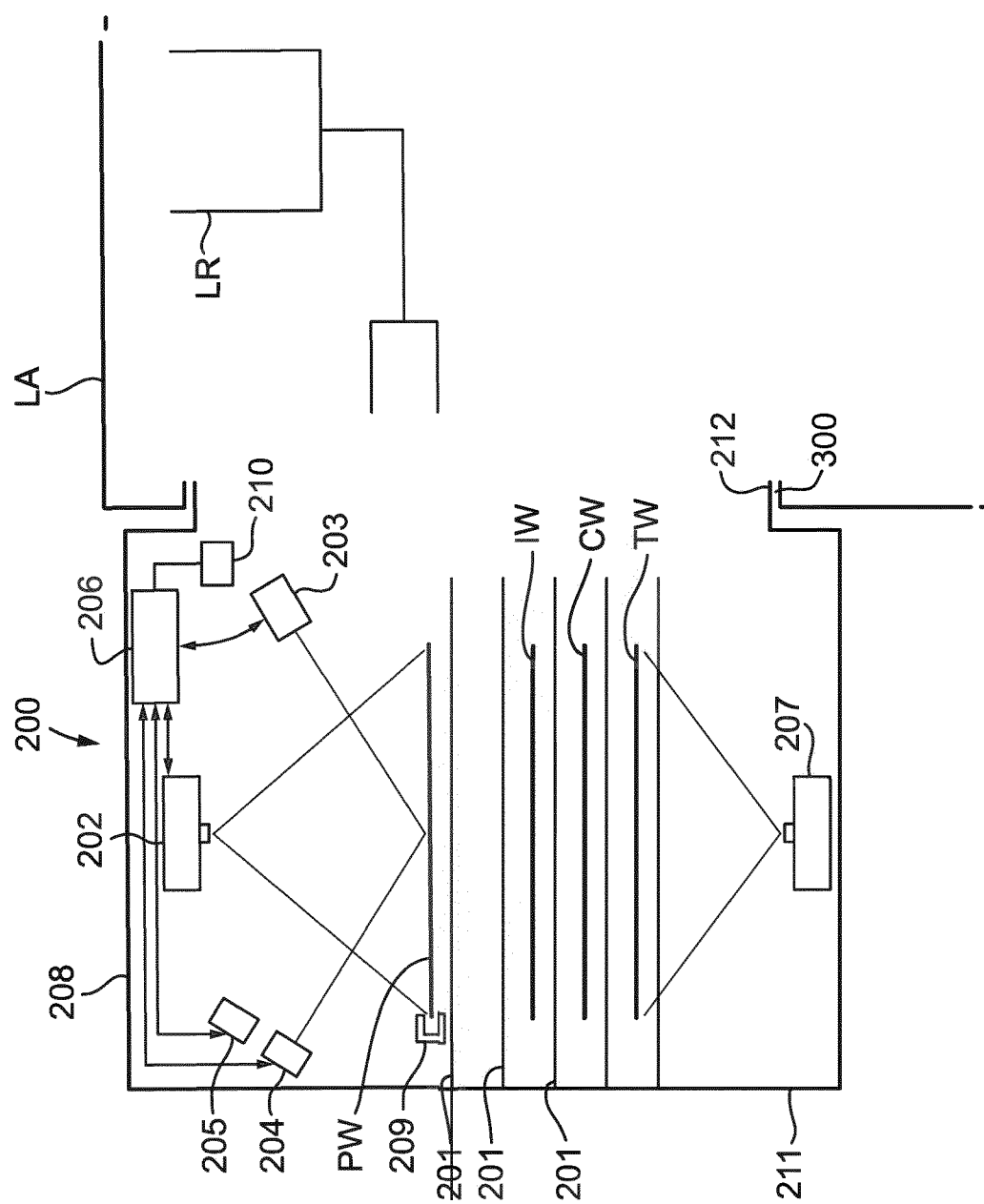


Fig. 5

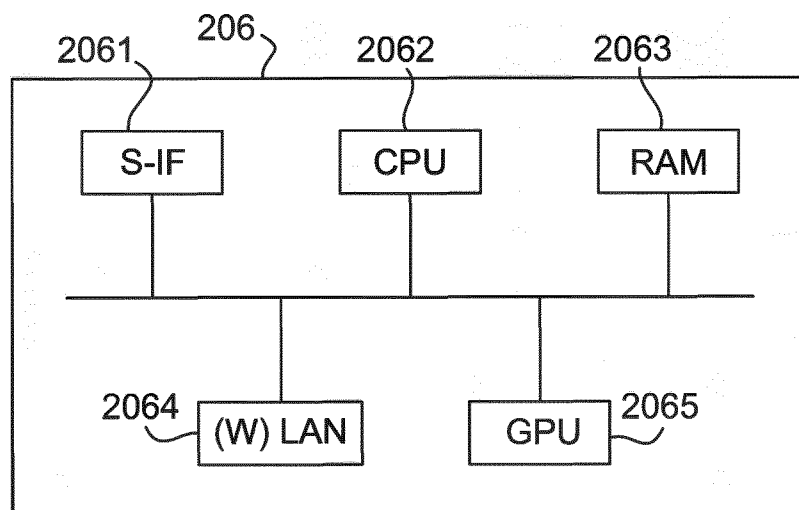
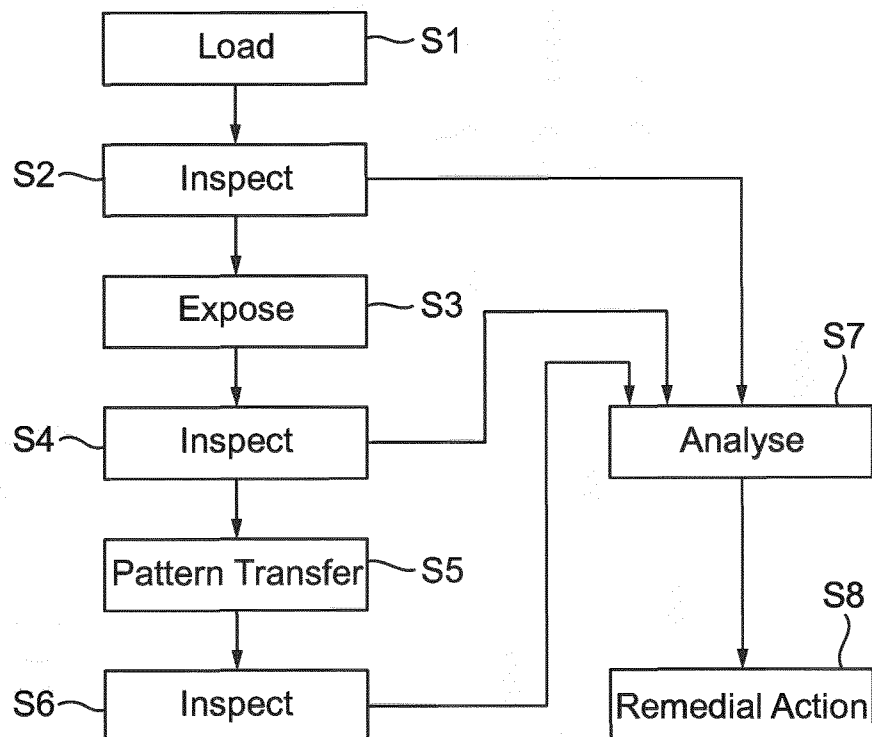


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/051987

A. CLASSIFICATION OF SUBJECT MATTER

INV. G03F7/20 G01N21/01 H01L21/673
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 H01L G01N

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

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Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

20 April 2020

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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

Andersen, Ole

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/051987

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