

(51) International Patent Classification:
G03F 7/20 (2006.01)(21) International Application Number:
PCT/EP2020/051355(22) International Filing Date:
21 January 2020 (21.01.2020)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
19156434.3 11 February 2019 (11.02.2019) EP

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

(72) Inventors: DE HOOGH, Joost; P.O. Box 324, 5500 AH Veldhoven (NL). NAKIBOGLU, Günes; P.O. Box 324, 5500 AH Veldhoven (NL). SCHMITZ, Roger, Wilhelmus, Antonius, Henricus; P.O. Box 324, 5500 AH Veldhoven (NL). VAN DE MOESDIJK, Remco, Yuri; P.O. Box 324, 5500 AH Veldhoven (NL). KÖK, Yücel; P.O. Box 324, 5500 AH Veldhoven (NL). TALEBAN FARD, Nafiseh; P.O. Box 324, 5500 AH Veldhoven (NL).

(74) Agent: PEI, Fei; P.O. Box 324, 5500 AH Veldhoven (NL).

(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, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, 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, GH, GM, KE, LR, LS, MW, MZ, NA, RW, 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, 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: LITHOGRAPHIC APPARATUS AND METHOD WITH A THERMAL CONTROL SYSTEM

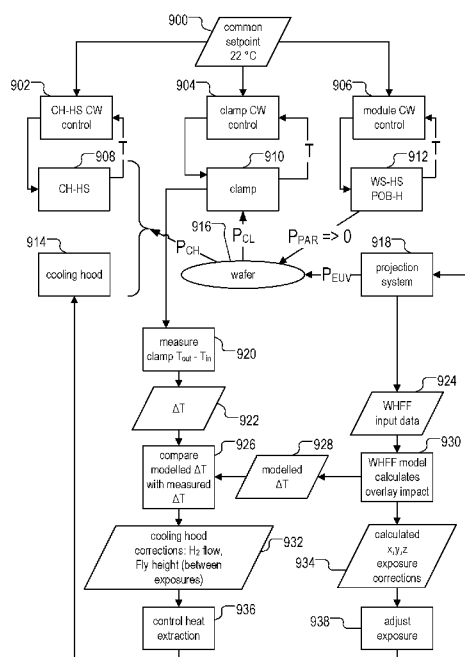


Fig. 9

(57) Abstract: A device comprising a compartment, said compartment comprising a wafer stage configured to hold a semiconductor wafer on a clamp, wherein the wafer stage is configured to follow a route within the compartment in operational use, the device comprising: a first component having a first surface facing a first portion of the route; a second component having a second surface facing a second portion of the route; a thermal control system operative to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

LITHOGRAPHIC APPARATUS AND METHOD WITH A THERMAL CONTROL SYSTEMCROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 19156434.3 which was filed on February 11, 2019 and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to a lithographic apparatus and a method of lithography.

10 BACKGROUND

[0003] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Lithography is widely recognized as one of the key steps in the manufacture of ICs and other devices and/or structures.

20 [0004] In order to reduce the minimum printable size, imaging may be performed using radiation having a short wavelength. It has therefore been proposed to use an EUV radiation source providing EUV radiation within the range of 13-14 nm, for example. It has further been proposed that EUV radiation with a wavelength of less than 10 nm could be used, for example within the range of 5-10 nm such as 6.7 nm or 6.8 nm. Such radiation is termed extreme ultraviolet (EUV) radiation or soft x-ray radiation.

25 [0005] Overlay error indicates the discrepancy between the actual location of the reticle pattern imaged onto the wafer and the desired location. There is a threshold to this error beyond which the result of the imaging is not acceptable. The order of magnitude is nanometers (in EUV) and shrinking with each next generation of EUV scanners. The process involves putting a next patterned layer onto a previous patterned layer in a stack of tens of layers that together will constitute eventually the integrated electronic circuit. A lateral displacement of one layer with another one might give rise to these layers being not properly connected, making the circuit unacceptable for operational use.

30 [0006] International patent application publication WO 2018/041599 is incorporated herein by reference. The publication discloses an EUV lithographic apparatus with a projection system which is configured to project via a slit a radiation beam, patterned by means of a mask, onto an exposure area on a substrate held on a substrate table. The substrate table is a component at the substrate stage and is in physical contact with the substrate and may be physically and functionally integrated with the

electrostatic clamp that clamps the substrate to the substrate table. The electrostatic clamp has a cooling system to transport away heat generated at the clamp. The lithographic apparatus operates in a scanning mode, wherein the mask and the substrate are scanned synchronously during the projection. A radiation beam used to project a pattern onto a substrate delivers a substantial amount of heat to that substrate, which causes localized heating of the substrate. Localized expansion of the substrate caused by the heating reduces the accuracy with which a projected pattern overlies patterns already present on the substrate. To address this problem, the lithographic apparatus disclosed in WO 2018/041599 comprises a cooling device located between the projection system and the substrate. The cooling device provides localized cooling of the substrate in the vicinity of the area where the patterned radiation beam is incident on the substrate via the slit. In some embodiments, a pre-exposure calibration operation may be performed to ensure that the amount of cooling that is provided to the substrate by the cooling device is within a desired range. As the calibration operation need not be performed with high frequency, the calibration operation may utilize measurements obtained from a substrate table cooling system, in addition to, or rather than, measurements obtained from sensors near to a cooling surface of the cooling device.

[0007] It is desirable not to remove more heat from the substrate than is added by the radiation beam. WO 2018/041599 discloses that in some embodiments, therefore, thermal shielding is provided in order to reduce cooling in areas adjacent the exposure area. In an embodiment, the thermal shield is provided with one or more channels to allow the thermal shield to be cooled and/or heated by flowing a temperature regulation fluid through the channels. The flow of temperature regulation fluid through the one or more channels may be configured to maintain the thermal shield at an ambient temperature such as, for example, around 22 °C.

[0008] However, there are still problems ensuring that the amount of cooling provided by the cooling device balances (i.e. compensates) the amount of radiation-beam heating. The substrate table is configured to follow a route within a compartment of the lithographic apparatus. It is a problem that surfaces facing the substrate held on a clamp can be at different temperature levels. This means that each surface causes a different unknown heat load to the substrate.

[0009] This unknown heat load can detrimentally affect the calibration operation and therefore the heat extraction by the cooling device. The resulting uncompensated radiation-beam heating can reduce the accuracy with which a projected pattern overlies patterns already present on the substrate, i.e. increasing overlay errors.

[0010] Furthermore, the unknown heat load can directly cause unwanted localized expansion of the substrate, in addition to that arising from radiation-beam heating. This further increases overlay errors.

SUMMARY

[0011] It is desirable to accurately control heat extraction of the cooling device to compensate for radiation-beam heating. Furthermore, it is desirable to reduce overlay errors caused by unwanted expansion of the substrate.

5 [0012] According to a first aspect of the present invention, there is provided a lithographic apparatus configured to project a patterned beam of radiation via projection optics onto a target portion of a semiconductor wafer held on a clamp at a wafer stage in a compartment, wherein the wafer stage is configured to follow a route within the compartment in operational use of the lithographic apparatus and wherein the lithographic apparatus comprises:

- 10 - a first component having a first surface facing a first portion of the route;
- a second component having a second surface facing a second portion of the route;
- a thermal control system operative to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

[0013] According to a second aspect of the present invention, there is provided a lithographic
15 method comprising:

- projecting a patterned beam of radiation via projection optics onto a target portion of a semiconductor wafer held on a clamp at a wafer stage in a compartment of a lithographic apparatus, wherein the lithographic apparatus comprises:
- a first component having a first surface facing a first portion of a route within the compartment; and
20 - a second component having a second surface facing a second portion of the route within the compartment;
- conveying the wafer stage along the route within the compartment; and
- operating a thermal control system to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

25

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] 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 corresponding parts, and in which:

30 [0015] Figure 1 depicts schematically a lithographic apparatus having reflective projection optics;

[0016] Figure 2 is a more detailed view of the apparatus of Figure 1 with a wafer-stage compartment;

[0017] Figure 3 illustrates schematically measurement and exposure processes in a dual-stage lithographic apparatus, according to known practice and modified in accordance with an embodiment
35 of the present invention;

[0018] Figure 4 depicts schematically a bottom-up view of the inside of a wafer-stage compartment of a lithographic apparatus;

[0019] Figure 5 depicts schematically a cross-section view of contents of a wafer-stage compartment of a lithographic apparatus;

[0020] Figure 6 depicts schematically a cross-section view of exposure of a wafer on a cooled clamp, with a cooling device to compensate for radiation-beam heating;

5 [0021] Figure 7 depicts schematically a cross-section view of exposure of a wafer on a cooled clamp, with a cooling device to compensate for radiation-beam heating, and with parasitic wafer and clamp heating;

[0022] Figure 8 depicts schematically an implementation of active thermal control with a thermal control system, in accordance with an embodiment of the present invention; and

10 [0023] Figure 9 depicts schematically an implementation of radiation-beam heating compensation with a cooling hood, with active thermal control of other components, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

15 [0024] Figure 1 schematically depicts a lithographic apparatus 100. The apparatus comprises:

[0025] - a source module SO;

[0026] - an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. EUV radiation);

[0027] - a support structure (e.g. a mask stage) MT constructed to support a patterning device (e.g. a mask or a reticle) MA and connected to a first positioner PM configured to accurately position the patterning device;

[0028] - a substrate stage (e.g. a wafer stage) WT constructed to hold a substrate (e.g. a resist coated wafer) W and connected to a second positioner PW configured to accurately position the substrate; and

25 [0029] - a projection system (e.g. a reflective projection 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.

[0030] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0031] The support structure MT holds the patterning device MA in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may include a frame or a table, for example, which may be fixed or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system.

[0032] The term “patterning device” should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. The pattern imparted to the radiation beam may correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

5 [0033] The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming
10 radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

[0034] The projection system, like the illumination system, may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, as appropriate for the exposure radiation being used,
15 or for other factors such as the use of a vacuum. It may be desired to use a vacuum for EUV radiation since other gases may absorb too much radiation. A vacuum environment may therefore be provided to the whole beam path with the aid of a vacuum wall and vacuum pumps.

[0035] As here depicted, the apparatus is of a reflective type (e.g. employing a reflective mask).

[0036] The lithographic apparatus may be of a type having two (dual stage) or more substrate stages
20 (and/or two or more mask stages). In such “multiple stage” machines the additional stages may be used in parallel, or preparatory steps may be carried out on one or more stages while one or more other stages are being used for exposure.

[0037] Referring to Figure 1, the illuminator IL receives an extreme ultra violet radiation beam from the source module SO. Methods to produce EUV light include, but are not necessarily limited to,
25 converting a material into a plasma state that has at least one element, e.g., xenon, lithium or tin, with one or more emission lines in the EUV range. In one such method, often termed laser produced plasma (“LPP”) the required plasma can be produced by irradiating a fuel, such as a droplet, stream or cluster of material having the required line-emitting element, with a laser beam. The source module SO may be part of an EUV radiation system including a laser, not shown in Figure 1, for providing the laser
30 beam exciting the fuel. The resulting plasma emits output radiation, e.g., EUV radiation, which is collected using a radiation collector, disposed in the source module. The laser and the source module may be separate entities, for example when a CO₂ laser is used to provide the laser beam for fuel excitation.

[0038] In such cases, the laser is not considered to form part of the lithographic apparatus and the
35 radiation beam is passed from the laser to the source module with the aid of a beam delivery system comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source

may be an integral part of the source module, for example when the source is a discharge produced plasma EUV generator, often termed as a DPP source.

[0039] The illuminator IL may comprise an adjuster for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as faceted field and pupil mirror devices. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross section.

[0040] The radiation beam B is incident on the patterning device (e.g., mask) MA, which is held on the support structure (e.g., mask stage) MT, and is patterned by the patterning device. After being reflected from the patterning device (e.g. mask) MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor PS2 (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate stage WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor PS1 can be used to accurately position the patterning device (e.g. mask) MA with respect to the path of the radiation beam B. Patterning device (e.g. mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

[0041] An EUV membrane, for example a pellicle PE, is provided to prevent contamination of the patterning device from particles within the system. Such pellicles may be provided at the location shown and/or at other locations. A further EUV membrane SPF may be provided as a spectral purity filter, operable to filter out unwanted radiation wavelengths (for example DUV). Such unwanted wavelengths can affect the photoresist on wafer W in an undesirable manner. The SPF may also optionally help prevent contamination of the projection optics within projection system PS from particles released during outgassing (or alternatively a pellicle may be provided in place of the SPF to do this). Either of these EUV membranes may comprise any of the EUV membranes disclosed herein.

[0042] The depicted apparatus could be used in a variety of modes. In a scan mode, the patterning device support (e.g., mask stage) MT and the substrate stage WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e., a single dynamic exposure). The speed and direction of the substrate stage WT relative to the patterning device support (e.g., mask stage) MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion. Other types of lithographic apparatus and modes of operation are possible, as is well-known in the art. For example, a step mode is known. In so-called “maskless” lithography, a programmable patterning device is held stationary but with a changing pattern, and the substrate stage WT is moved or scanned.

[0043] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0044] Figure 2 shows an embodiment of the lithographic apparatus in more detail, including a radiation system 42, the illumination system IL, and the projection system PS. The radiation system 42 as shown in Figure 2 is of the type that uses a laser-produced plasma as a radiation source. EUV radiation may be produced by a very hot plasma created from, for example, xenon (Xe), lithium (Li) or tin (Sn). In an embodiment, Sn is used to create the plasma in order to emit the radiation in the EUV range.

[0045] The radiation system 42 embodies the function of source SO in the apparatus of Figure 1. Radiation system 42 comprises a source chamber 47, in this embodiment not only substantially enclosing a source of EUV radiation, but also collector 50 which, in the example of Figure 2, is a normal-incidence collector, for instance a multi-layer mirror.

[0046] As part of an LPP radiation source, a laser system 61 is constructed and arranged to provide a laser beam 63 which is delivered by a beam delivering system 65 through an aperture 67 provided in the collector 50. Also, the radiation system includes a target material 69, such as Sn or Xe, which is supplied by target material supply 71. The beam delivering system 65, in this embodiment, is arranged to establish a beam path focused substantially upon a desired plasma formation position 73.

[0047] In operation, the target material 69, which may also be referred to as fuel, is supplied by the target material supply 71 in the form of droplets. A trap 72 is provided on the opposite side of the source chamber 47, to capture fuel that is not, for whatever reason, turned into plasma. When such a droplet of the target material 69 reaches the plasma formation position 73, the laser beam 63 impinges on the droplet and an EUV radiation-emitting plasma forms inside the source chamber 47. In the case of a pulsed laser, this involves timing the pulse of laser radiation to coincide with the passage of the droplet through the position 73. These create a highly ionized plasma with electron temperatures of several 10^5 K. The energetic radiation generated during de-excitation and recombination of these ions includes the wanted EUV which is emitted from the plasma at position 73. The plasma formation position 73 and the aperture 52 are located at first and second focal points of collector 50, respectively and the EUV radiation is focused by the normal-incidence collector mirror 50 onto the intermediate focus point IF.

[0048] The beam of radiation emanating from the source chamber 47 traverses the illumination system IL via reflectors 53, 54, as indicated in Figure 2 by the radiation beam 56. The reflectors direct the beam 56, via pellicle PE, onto a patterning device (e.g. reticle or mask) positioned on a support (e.g. reticle stage or mask stage) MT. A patterned beam 57 is formed, which is imaged by projection system PS via reflective elements 58, 59 onto a substrate carried by wafer stage or substrate stage WT. The substrate W is held on the substrate stage WT by an electrostatic clamp CL. The substrate stage WT with its camp CL is housed in a wafer-stage compartment WSC.

[0049] The projection system PS has projection optics mounted in a container (box) providing a specific low-pressure environment. This is known as a projection optics box (POB). The POB and the

wafer-stage compartment WSC are separate environments. During exposure, the photoresist may be outgassing owing to the radiation received from the POB. These gasses should not reach the projection optics as they may contaminate the surfaces of the mirrors (the POB contains reflective optical components in EUV). Contamination may then interfere with the imaging. Therefore, a dynamic gas lock DGL (not shown) is provided to reduce such contamination.

[0050] More elements than shown may generally be present in illumination system IL and projection system PS. For example there may be one, two, three, four or even more reflective elements present, rather than the two elements 58 and 59 shown in Figure 2.

[0051] As the skilled person will know, reference axes X, Y and Z may be defined for measuring and describing the geometry and behavior of the apparatus, its various components, and the radiation beams 55, 56, 57. At each part of the apparatus, a local reference frame of X, Y and Z axes may be defined. The Z axis broadly coincides with the direction of optical axis O at a given point in the system, and is generally normal to the plane of a patterning device (reticle) MA when describing the spatial relationships with reference to the patterning device and normal to the plane of substrate W when describing the spatial relationships with reference to the substrate W. In the source module (apparatus) 42, the X axis coincides broadly with the direction of fuel stream (69, described below), while the Y axis is orthogonal to that, pointing out of the page as indicated. On the other hand, in the vicinity of the support structure MT that holds the reticle MA, the local X axis is generally transverse to a scanning direction aligned with the local Y axis. For convenience, in this area of the schematic diagram Figure 2, the X axis points out of the page, again as marked. These designations are conventional in the art and will be adopted herein for convenience. In principle, any reference frame can be chosen to describe the apparatus and its behavior.

[0052] In addition to the wanted EUV radiation, the plasma may produce other wavelengths of radiation, for example in the infrared, visible, UV (ultraviolet) and DUV (deep ultraviolet) ranges. There may also be IR (infrared) radiation present from the laser beam 63. The non-EUV wavelengths are not wanted in the illumination system IL and projection system PS and various measures may be deployed to block the non-EUV radiation. As schematically depicted in Figure 2, a spectral purity filter SPF may be applied upstream of the virtual source point IF, for IR, DUV and/or other unwanted wavelengths. In the specific example shown in Figure 2, two spectral purity filters are depicted, one within the source chamber 47 and one at the output of the projection system PS.

[0053] Figure 3 illustrates the steps to expose target portions (e.g. dies) on a substrate W in a dual stage lithographic apparatus. The two substrate stages (also known as wafer stages) are configured to follow a route within the wafer-stage compartment (WSC in Figure 2) in operational use of the lithographic apparatus. The substrate starts in a pre-aligner and is transferred to a substrate stage that holds the substrate in the clamp. The substrate is then conveyed along a route indicated by the steps 200, 202, 204, 210, 212, 214, 216, 218, 210 and 220.

[0054] The vacuum pre-aligner VPA is part of the wafer handler. The pre-aligner is a robot that puts the substrate W' into the correct orientation (in the local X-Y plane) so that the substrate W' has the correct orientation when transferred to the substrate stage at step 200 and is ready for the measure operation MEA.

5 [0055] Within the left-hand dashed box are steps performed at a measurement station MEA, while the right-hand side dashed box shows steps performed at the exposure station EXP. From time to time, one of the substrate stages WTa, WTb will be at the exposure station, while the other is at the measurement station, as described above. At step 200, a new substrate W' is loaded from the vacuum pre-aligner VPA by a mechanism not shown. These two substrates are processed in parallel (one at the
10 measurement station and another one at the expose station) in order to increase the throughput of the lithographic apparatus.

[0056] Referring initially to the newly-loaded substrate W', this may be a previously unprocessed substrate, prepared with a new photo resist for first time exposure in the apparatus. In general, however, the lithography process described will be merely one step in a series of exposure and processing steps,
15 so that substrate W' has been through this apparatus and/or other lithography apparatuses, several times already, and may have subsequent processes to undergo as well. Particularly for the problem of improving overlay performance, the task is to ensure that new patterns are applied in exactly the correct position on a substrate that has already been subjected to one or more cycles of patterning and processing. These processing steps progressively introduce distortions in the substrate that must be
20 measured and corrected for, to achieve satisfactory overlay performance.

[0057] The previous and/or subsequent patterning step may be performed in other lithography apparatuses, as just mentioned, and may even be performed in different types of lithography apparatus. For example, some layers in the device manufacturing process which are very demanding in parameters such as resolution and overlay may be performed in a more advanced lithography tool than other layers
25 that are less demanding. Therefore, some layers may be exposed in an immersion type lithography tool, while others are exposed in a 'dry' tool or in a vacuum tool. Some layers may be exposed in a tool working at DUV wavelengths, while others are exposed using EUV wavelength radiation.

[0058] At 202, alignment measurements using the substrate marks P1 (depicted as four crosses) etc. and image sensors (not shown) are used to measure and record alignment of the substrate relative to
30 substrate stages WTa/WTb. In addition, several alignment marks across the substrate W' will be measured using alignment sensor AS. These measurements are used in one embodiment to establish a "wafer grid", which maps very accurately the distribution of marks across the substrate, including any distortion relative to a nominal rectangular grid.

[0059] At step 204, a map of wafer height (Z) against X-Y position is measured also using the level
35 sensor LS. Conventionally, the height map is used only to achieve accurate focusing of the exposed pattern. Primarily, the height map is used only to achieve accurate focusing of the exposed pattern. It may be used for other purposes in addition.

[0060] When substrate W' was loaded, recipe data 206 were received, defining the exposures to be performed, and also properties of the wafer and the patterns previously made and to be made upon it. To these recipe data are added the measurements of wafer position, wafer grid and height map that were made at 202, 204, so that a complete set of recipe data and measurement data 208 can be passed to the exposure station EXP. The measurements of alignment data for example comprise X and Y positions of alignment targets formed in a fixed or nominally fixed relationship to the product patterns that are the product of the lithographic process. These alignment data, taken just before exposure, are used to generate an alignment model with parameters that fit the model to the data. These parameters and the alignment model will be used during the exposure operation to correct positions of patterns applied in the current lithographic step. The model in use interpolates positional deviations between the measured positions. A conventional alignment model might comprise four, five or six parameters, together defining translation, rotation and scaling of the 'ideal' grid, in different dimensions. Advanced models are known that use more parameters.

[0061] At 210, wafers W' and W are swapped, so that the measured substrate W' becomes the substrate W entering the exposure station EXP. In the example apparatus of Figure 1, this swapping is performed by exchanging the substrate stages WTa and WTb within the apparatus, so that the substrates W, W' remain accurately clamped and positioned on those supports, to preserve relative alignment between the substrate stages and substrates themselves. Accordingly, once the stages have been swapped, determining the relative position between projection system PS and substrate stage WTb (formerly WTa) is all that is necessary to make use of the measurement information 202, 204 for the substrate W (formerly W') in control of the exposure steps. At step 212, reticle alignment is performed using mask alignment marks (not shown). In steps 214, 216, 218, scanning motions and radiation are applied at successive target locations across the substrate W, in order to complete the exposure of a number of patterns.

[0062] By using the alignment data and height map obtained at the measuring station in the performance of the exposure steps, these patterns are accurately aligned with respect to the desired locations, and, in particular, with respect to features previously laid down on the same substrate. The exposed substrate, now labeled W'' is unloaded from the apparatus at step 220, to eventually undergo etching or other processes, in accordance with the exposed pattern.

[0063] The skilled person will know that the above description is a simplified overview of a number of very detailed steps involved in one example of a real manufacturing situation. For example, rather than measuring alignment in a single pass, often there will be separate phases of coarse and fine measurement, using the same or different marks. The coarse and/or fine alignment measurement steps can be performed before or after the height measurement, or interleaved.

[0064] Embodiments may include a scanner with cooling hood or cooling device. The scanner has components with surfaces that are in line of sight of the wafer some time or another. The components are all thermally conditioned to have them assume the same temperature.

[0065] The lithographic scanner has a cooling device for extracting from the wafer the heat, which is generated by absorption of the imaging radiation by the wafer.

[0066] The cooling power of the cooling device needs to be controlled very accurately and the required cooling power depends on many parameters.

5 [0067] The values of these parameters may vary per scenario and are taken into account in a Wafer Heating Feed Forward (WHFF) model, described below.

[0068] A mismatch between the heat extracted and the heat generated gives rise to thermally induced deformation of the wafer that causes overlay errors: unintended lateral displacement of the location of the pattern imaged with respect to the desired location.

10 [0069] The cooling device needs to be calibrated with respect to the imaging radiation received at the wafer. An example of a calibration mechanism used involves monitoring the difference between the temperature of the cooling water of the electrostatic clamp at the clamp's entrance and the temperature of the cooling water at the clamp's exit.

[0070] A temperature difference is indicative of the heat absorbed (or heat released) by the cooling
15 water during its passing through the wafer-clamp. Ideally, the temperature difference of the cooling water between entrance and exit is representative of the mismatch between the heat extracted by the cooling device and the heat generated in the wafer by the radiation received from the imaging radiation beam.

[0071] However, the wafer-clamp's cooling water is also exposed to parasitic heat-loads, in addition
20 to the heat load from the exposure radiation. Examples of components in the scanner that represent a parasitic heat load are those having a surface facing the wafer stage on its route through the wafer-stage compartment. As a result, the parasitic heat loads interfere with control of the heat extraction by the cooling device.

[0072] Figure 4 depicts schematically an example of a bottom-up view of the inside of a wafer-
25 stage compartment of a lithographic apparatus. This is what would be seen looking up from the point of view of the wafer. The wafer handler WH is at the left-hand side. The vacuum pre-aligner VPA shown in Figure 3 is part of the wafer handler. The measurement station MEA has a wafer-stage heat shield with two components WS-HS-A and WS-HS-B. The exposure station EXP has a wafer stage heat shield with two components WS-HS-C and WS-HS-D. Also, at the exposure station EXP, the
30 cooling hood heat shield component CH-HS is shown next to the projection optics box hatch component POB-H. The exposure is performed through the gap between the cooling hood heat shield CH-HS and the projection optics box hatch POB-H. These components face different portions of the route followed by the wafer stage as described with reference to Figure 3.

[0073] The metrology frame MF is shown by cross-hatched elements. A metrology frame is a
35 trustworthy sub-system that serves as a reference for metrology components, e.g., components that measure the position of the wafer stage accurately and that measure the topography of the wafer. The metrology frame is a mechanically very stiff construction that is kept at a stable and precise temperature

so as to minimize inaccuracies in the measurements owing to thermally induced deformation of the metrology frame.

[0074] Figure 5 depicts schematically a cross-section view of contents of a wafer-stage compartment of a lithographic apparatus. The metrology frame MF is again shown with cross-hatching.

5 The wafer handler has a component WH above the wafer W. It also has a component below the wafer, in the form of the vacuum pre-aligner VPA. Spanning the measurement station MEA and exposure station EXP, the wafer-stage heat shield components WS-HS-A and WS-HS-B are shown above the wafer W supported by the clamp CL. In the exposure station EXP, the cooling hood heat shield component CH-HS and projection optics box hatch component POB-H are shown above another wafer
10 W supported by its respective clamp CL. In the absence of operation of embodiments described below, the surfaces of the components WH, WS-HS-A/B/C/D, CH-HS and POB-H can have different temperatures, leading to many parasitic heat loads to the wafer. The parasitic heat loads interfere with control of heat extraction by the cooling device, which will now be described with reference to Figure 6 and 7.

15 [0075] Figure 6 depicts schematically a cross-section view of exposure of a wafer on a cooled clamp, with a cooling device to compensate for radiation-beam heating. A cooling hood CH and its heat shield CH-HS (such as the cooling element and heat shield as disclosed in WO 2018/041599) are provided to provide a localized cooling power P_{CH} to the wafer W. The aim of the cooling is to balance the localized cooling power P_{CH} with the radiation-beam heating power P_{EUV} .

20 [0076] The cooling hood CH functions to remove heat from the wafer W to prevent slip and reduce the raw overlay impact. In order to transport heat from wafer to cooling hood, hydrogen gas is provided, e.g., via the cooling hood, between the cooling hood finger (that is the part of the cooling hood reaching down closest to the wafer) and the wafer W that serves to transport the heat.

[0077] The required cooling power of the cooling hood CH is determined by

$$P_{CH} = h(p, T, z, TAC) * A * \Delta T_{CH-wafer}$$

25 where h is the heat transfer coefficient (depending on pressure, temperature and fly height and TAC), A is the surface area, $\Delta T_{CH-wafer}$ is the temperature difference between cooling hood and wafer. Fly height is the distance between the (stationary) cooling hood and wafer on the (moving) wafer stage WT. TAC is the thermal accommodation coefficient of both surfaces and is a physical quantity
30 characterizing the behavior of gas or vapor particles in their collisions with a solid or liquid body surface. The value of the accommodation coefficient depends on the surface nature and state as well as on the composition and pressure of the gas mixture in the environment and on other parameters.

[0078] The power that needs to be extracted from the wafer differs per product layer and ideally should be balanced perfectly with the EUV power and fed into a wafer heating feed forward model
35 (WHFF model). The WHFF model enables one to anticipate the temperature difference (928 in Figure 9) to be neutralized by activating cooling hood heaters or coolers. The model can also predict the raw

overlay impact (934 in Figure 9) which can be corrected by the optical system of the POB (918 in Figure 9).

[0079] Inputs to the WHFF model may include:

- EUV power;
- 5 • Reticle reflection profile;
- Effective IR power in the wafer/clamp;
- Cooling hood power P_{CH} ;
- Scan speed;
- Clamp cooling water flow rate; and
- 10 • DGL load profile.

[0080] Any mismatch in power between the model and reality may cause a contribution to the overlay error.

[0081] To reduce overlay error due to power mismatch, the cooling hood power is calibrated with respect to the EUV power. This calibration is performed by a power measurement within the clamp. As
15 the system may drift, the balance is monitored continuously.

[0082] By comparing the measured temperature difference ΔT over the clamp with the modelled value of the WHFF model, any imbalance can be corrected, at least, when the imbalance is caused by the cooling hood and not by unknown parasitic heat loads.

[0083] The clamp CL is thermally controlled with cooling water CW. By monitoring the
20 temperature of the cooling water $T_{out}-T_{in}$ (ΔT between entering and exiting cooling water), information can be determined on how much heat P_{CH} the cooling hood CH is extracting.

[0084] When the flowrate is known and stable, the temperature difference ΔT over the clamp CL is a measure for the cooling hood power P_{CH} . In the ideal situation, there are no parasitic heat loads to the wafer and the measured power in the clamp is the balance between EUV and cooling hood. Different
25 parasitic heat loads act on the wafer/clamp and these will interfere with the power measurement, and these are now described with reference to Figure 7.

[0085] Figure 7 depicts schematically a cross section of exposure of a wafer on a cooled clamp, with a cooling device to compensate for radiation-beam heating, and with parasitic wafer and clamp heating.

[0086] Figure 7 includes all the elements of Figure 6, but with the addition of parasitic heat loads. The hydrogen gas that serves to transport heat from the wafer W to the cooling hood CH can disperse in the compartment and also transport heat from surfaces facing the wafer W and the clamp CL. This gives rise to heat loads. For example, the wafer-stage heat shield components WS-HS-C and WS-HS-D shown in Figures 4 and 5 have surfaces that can provide a power P_{WS-HS} to the clamp via the wafer.
35 Furthermore, for example, the POB hatch component POB-H shown in Figures 4 and 5 has surfaces that can provide a power P_{POB-H} to the clamp via the wafer. Furthermore, the metrology frame MF shown

in Figures 4 and 5 and sensors attached to it have surfaces that can provide a power P_{MF} to the clamp via the wafer. This can be the case if the clamp CL is thermally controlled at a temperature set-point different from that of the metrology frame MF.

[0087] When the wafer stage WT proceeds on its route through the wafer stage compartment, it passes by other components having surfaces facing respective portions of the route. These surfaces can give rise to parasitic heat loads. For example, the wafer handler WH can provide a power P_{WH} to the clamp via the wafer. Similarly, when the wafer is being oriented and thermally conditioned on the vacuum pre-aligner VPA, surfaces of the vacuum pre-aligner can provide a power P_{VPA} (not shown) to the clamp via transfer of the wafer from the VPA to the clamp.

[0088] Via the wafer and clamp the parasitic heat loads are summed as a parasitic power P_{PAR} and added to the clamp cooling power P_{CL} arising from the imbalance of the radiation-beam heating power P_{EUV} and the cooling hood power P_{CH} . The powers P_{PAR} and P_{CL} arising from the heat loads are integrated into one cooling water CW temperature difference $T_{out}-T_{in}$. This makes it impossible to distinguish the actual source of the imbalance using the cooling water CW temperature difference $T_{out}-T_{in}$. A second problem with parasitic heat loads is that they will directly heat the wafer during expose which causes thermal expansion and an additional overlay error.

[0089] Embodiments in the invention create a mini-environment in the wafer-stage compartment to cancel the parasitic heat loads. This then enables inline (in operational use) calibration and accurate control of the cooling hood power.

[0090] The parasitic heat loads may be cancelled by means of giving surfaces, which are facing a wafer some time or another, the same (or very close to the same) stable temperature.

[0091] These surfaces include the wafer clamp at the wafer stage, as well as the heat shields in the lithographic apparatus' wafer-stage compartment wherein the wafer stage moves about.

[0092] Preferably, the temperature of each of these surfaces is actively controlled to maintain the temperature set-point, regardless of these surfaces receiving a varying heat load themselves in operational use of the lithographic apparatus.

[0093] To allow for inline cooling hood calibration, the parasitic heat loads are to be removed from the equation. This is done by the wafer-stage compartment thermal mini environment. This basically means that most or all wafer facing surfaces, including the clamp and wafer handler are actively controlled to the same temperature level. This is called Active Thermal Control.

[0094] As discussed above, in the absence of Active Thermal Control, all surfaces facing the wafer stage as shown on Figure 4 can be at a different temperature level. This means that each surface causes a different unknown heat load (via hydrogen conduction or radiation) to the wafer. This acts detrimentally on both the inline calibration and the direct overlay effect.

[0095] In an initial state, all the wafer facing surfaces can have a different temperature offset.

[0096] In an equal temperature state, all surfaces are calibrated with respect to each other to the same temperature, but this temperature can be different from the metrology frame. There is a significant

surface area (cross-hatched in Figure 4) still at an offset, which still causes parasitic heat loads to the wafer/clamp.

[0097] In an optimally thermally-matched state, by lowering the setpoint of the wafer facing surfaces towards that of the metrology frame (22 °C), there is no temperature difference between any of the surfaces anymore. At this point, all parasitic heat loads from the wafer facing surfaces are minimized.

[0098] To ensure that the temperature of each wafer-facing surface remains stable under the varying loads that are applied during exposure, Active Thermal Control is used. This means that each module gets a separate control loop with, e.g., a cooling water heater or cooler to maintain the setpoint, similar to the clamp. This approach is repeated for all wafer facing surfaces. To enable all surfaces to be actively controlled to the same set point, for example exactly 22 °C, the cooling water can be pre-cooled by approximately 100mK below 22 °C. To cool the cooling water there are, for example, several options:

- Separate Peltier elements per branch;
- One single Peltier element, pre-cooling all branches;
- Separate cabinet at a lowered setpoint; and
- Single cabinet with multiple outputs, each at a different temperature.

[0099] Figure 8 depicts schematically an implementation of Active Thermal Control with a thermal control system, in accordance with an embodiment of the present invention.

[0100] A cabinet CAB pumps cooling water in a circuit through components in the wafer-stage compartment via manifolds MAN. The components are the vacuum pre-aligner VPA, electrostatic clamp CL, mirror block MB, wafer stage heat shield WS-HS (representing WS-HS-A/B/C/D in Figure 4, each having independent thermal control), cooling hood heat shield CH-HS and POB hatch POB-H. A separate Active Thermal Control Unit ACTU is put outside the vacuum VAC and holds all the heaters H to control the cooling water setpoints for each branch individually. There are several additional temperature sensors needed for control (each depicted by a circle enclosing a cross). The sensors are used to control the ingoing cooling water temperature by measuring cooling water temperature difference ΔT_H across the respective heater H. The sensors on the components are used to suppress the dynamic heat loads in the system by measuring cooling water temperature difference ΔT_C across the respective component. Alternatively (not shown), the sensors can be positioned in the return branch of the module. The valve V is used to set flow rate for calibration, under control of the ATCU.

[0101] The top components VPA, CL, MB are thermally controlled independently. They are operative to maintain a temperature at a common set-point magnitude (22 °C in this example), but how they control the water temperature is separate from the ATCU. Because they also use the water to actively control the wafer temperature, the feedback loop has to be faster (with the heaters mounted on the components) than what the ATCU controller can provide, in this example. The ATCU and the independent temperature controllers together make up the thermal control system.

[0102] Figure 9 depicts schematically an implementation of radiation-beam heating compensation with a cooling hood, with active thermal control of other components, in accordance with an embodiment of the present invention.

[0103] A lithographic apparatus is configured to project a patterned beam of radiation via projection optics 918 onto a target portion of a semiconductor wafer 916 held on a clamp 910 at a wafer stage in a compartment (WSC in Figure 2). The wafer stage is configured to follow a route within the compartment in operational use of the lithographic apparatus (as described with reference to Figure 3). A vacuum is maintained in the compartment, which is essential for use with EUV lithography with an opening between the wafer-stage compartment and the POB. The vacuum also has the effect of removing unwanted hydrogen used with the cooling device, to reduce parasitic heat transfer from other components to the wafer and clamp in the compartment.

[0104] The lithographic apparatus has a first component, e.g. cooling device heat shield component (CH-HS in Figures 4-7), having a first surface 908 facing a first portion of the route. The cooling device heat shield is arranged to shield at least part of the cooling device from the wafer stage.

[0105] The lithographic apparatus has a second component, e.g. a wafer stage heat shield component (WS-HS-A/B/C/D in Figures 4 and 5), having a second surface 912 facing a second portion of the route.

[0106] A thermal control system 902, 906 is operative to maintain a first temperature of the first surface 908 and a second temperature of the second surface 912 at a common set-point magnitude 900, in this example 22 °C. This has the effect of reducing parasitic heat loads and variation in the parasitic heat loads, which improves the cooling device cooling calibration, thus reducing overlay errors.

[0107] If there is a temperature offset between the set point of the clamp and the common set point of the first and second surfaces, then the parasitic heat load will be constant and can be modeled or accounted for by calibration. However, the thermal control system 904 may be operative to maintain a third temperature of the clamp 910 at the common set-point magnitude 900. This has the beneficial effect of making the parasitic heat loads tend to zero, because all or most of the surfaces facing the wafer, including the clamp under the wafer and the component surface above the wafer, are thermally controlled using the common set-point magnitude. A common set-point magnitude means that the set point is identical, or within the range of thermal control tolerances of the surfaces. Preferably, instances of the common set points for control of each component or surface are the same. Alternatively, instances of common set points may differ by preferably less than 0.05°C, or more preferably less than 0.005°C. Thus, instances of the common set point should close enough such that the parasitic heat loads are reduced to be significantly less than the clamp cooling power, preferably less than 5% of the clamp cooling power, more preferably less than 1% of the clamp cooling power.

[0108] Additionally, or alternatively, surfaces of other heat shields components (such as the POB hatch as described with reference to Figures 4 and 5) or the metrology frame (MF as described with

reference to Figures 4 and 5) may be maintained at the common set-point magnitude 900. These have the effect of reducing parasitic heat loads and variation in the parasitic heat loads.

[0109] A cooling device 914 (CH in Figures 6 and 7) is positioned underneath the projection optics (PS in Figure 2) and configured to extract from the target portion heat that is generated via absorption of the radiation. The cooling device has the effect of reducing overlay errors, as described above. The heat extraction P_{CH} of the cooling device 914, shielded by the its heat shield 908, is controlled based on measurements 920 of cooling of the clamp, ΔT 922. This is useful because direct measurements of cooling device power, such as measuring coolant liquid of the cooling device, do not accurately reflect the localized cooling on the wafer. Measurements of cooling of the clamp provide a simple measurement of the imbalance between the cooling device power and the radiation-beam heating power, once the common set point is achieved at the surfaces facing the wafer-stage route. The measurements of cooling of the clamp in this example comprise measurement of a cooling water CW temperature gradient ($T_{out} - T_{in}$, as shown in Figure 7) and mass-flow rate. Such measurements have the advantage of being relatively simple.

[0110] The lithographic apparatus is operable to control the projection system 918 to adjust 938 the patterned beam of radiation to compensate for substrate deformation using the WHFF model 930 based on the heat extraction P_{CH} of the cooling device. The WHFF model 930 and its input data 924 are described above with reference to Figure 6. The WHFF model calculates x,y, and z exposure corrections 934 that are used to adjust 938 the patterned beam of radiation. Adjusting the patterned beam of radiation has the effect of reducing overlay errors. The integrity of the adjustment is maintained by controlling temperature to the common set point at the surfaces facing the wafer-stage route.

[0111] The lithographic apparatus further comprises a wafer pre-aligner (VPA in Figure 5) operable to orient and thermally condition the wafer before transfer to the clamp 910. The thermal control system is operative to maintain a fourth temperature of the wafer pre-aligner at the common set-point magnitude 900. This is not shown in Figure 9, but it is essentially the same as the control 906 of the wafer handler heat shield component surface 912. Controlling the temperature of the pre-aligner in this way has the effect of reducing parasitic heat loads on the wafer and clamp.

[0112] Embodiments remove almost all parasitic heat loads from the wafer facing surfaces towards the clamp. Embodiments also reduce direct heat-load impact of wafer facing surfaces, which cause thermal expansion of the wafer, thus further reducing overlay errors.

[0113] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g., having a wavelength of or about 365, 355, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV) radiation (e.g., having a wavelength in the range of 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[0114] The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic and electrostatic optical components.

[0115] The breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

Clause 1. A lithographic apparatus configured to project a patterned beam of radiation via projection optics onto a target portion of a semiconductor wafer held on a clamp at a wafer stage in a compartment, wherein the wafer stage is configured to follow a route within the compartment in operational use of the lithographic apparatus and wherein the lithographic apparatus comprises: - a first component having a first surface facing a first portion of the route; - a second component having a second surface facing a second portion of the route; - a thermal control system operative to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

Clause 2. The lithographic apparatus of clause 1 wherein the thermal control system is operative to maintain a third temperature of the clamp at the common set-point magnitude.

Clause 3. The lithographic apparatus of clause 1 or clause 2 further comprising a cooling device positioned underneath the projection optics and configured to extract from the target portion heat that is generated via absorption of the radiation, wherein heat extraction of the cooling device is controlled based on measurements of cooling of the clamp.

Clause 4. The lithographic apparatus of clause 3, wherein the measurements of cooling of the clamp comprise measurement of a cooling water temperature gradient and mass-flow rate.

Clause 5. The lithographic apparatus of clause 3 or clause 4, wherein the lithographic apparatus is operable to control the projection system to adjust the patterned beam of radiation to compensate for substrate deformation using a model based on the heat extraction of the cooling device.

Clause 6. The lithographic apparatus of any preceding clause further comprising a wafer pre-aligner operable to orient and thermally condition the wafer before transfer to the clamp and wherein the thermal control system is operative to maintain a fourth temperature of the wafer pre-aligner at the common set-point magnitude.

Clause 7. The lithographic apparatus of any preceding clause wherein in operational use of the lithographic apparatus a vacuum is maintained in the compartment.

Clause 8. The lithographic apparatus of any preceding clause, wherein a component comprises device cooling device heat shield, arranged to shield at least part of the cooling device from the wafer stage.

Clause 9. The lithographic apparatus of any preceding clause, wherein a component comprises a heat shield.

Clause 10. The lithographic apparatus of any preceding clause, wherein a component comprises a metrology frame.

Clause 11. A lithographic method comprising: - projecting a patterned beam of radiation via projection optics onto a target portion of a semiconductor wafer held on a clamp at a wafer stage in a compartment of a lithographic apparatus, wherein the lithographic apparatus comprises: - a first component having a first surface facing a first portion of a route within the compartment; and - a second component having

a second surface facing a second portion of the route within the compartment; - conveying the wafer stage along the route within the compartment; and - operating a thermal control system to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

5 Clause 12. The lithographic method of clause 11 further comprising operating the thermal control system to maintain a third temperature of the clamp at the common set-point magnitude.

Clause 13. The lithographic method of clause 11 or clause 12 further comprising operating a cooling device positioned underneath the projection optics to extract from the target portion heat that is generated via absorption of the radiation, wherein heat extraction of the cooling device is controlled
10 based on measurements of cooling of the clamp.

Clause 14. The lithographic method of clause 13, wherein the measurements of cooling of the clamp comprise measurement of a cooling water temperature gradient and mass-flow rate.

Clause 15. The lithographic method of clause 13 or clause 14, comprising controlling the projection system to adjust the patterned beam of radiation to compensate for substrate deformation using a model
15 based on the heat extraction of the cooling device.

Clause 16. The lithographic method of any of clauses 11 to 15 further comprising to orienting and thermally conditioning the wafer using a wafer pre-aligner before transfer to the clamp and operating the thermal control system to maintain a fourth temperature of the wafer pre-aligner at the common set-point magnitude.

20 Clause 17. The lithographic method of any of clauses 11 to 16 further comprising maintaining a vacuum in the compartment.

Clause 18. The lithographic method of any of clauses 11 to 17, wherein a component comprises device cooling device heat shield, arranged to shield at least part of the cooling device from the wafer stage.

Clause 19. The lithographic method of any of clauses 11 to 18, wherein a component comprises a heat
25 shield.

Clause 20. The lithographic method of any of clauses 11 to 19, wherein a component comprises a metrology frame.

CLAIMS

1. A device comprising a compartment, said compartment comprising a wafer stage configured to hold a semiconductor wafer on a clamp, wherein the wafer stage is configured to follow a route within the compartment in operational use, the device comprising:
 - 5 - a first component having a first surface facing a first portion of the route;
 - a second component having a second surface facing a second portion of the route;
 - a thermal control system operative to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.
- 10 2. The device of claim 1 wherein the thermal control system is operative to maintain a third temperature of the clamp at the common set-point magnitude.
3. The device of claim 1 or claim 2 further comprising a cooling device positioned underneath projection optics through which a patterned beam of radiation is projected onto a target portion of the
15 semiconductor wafer, the cooling device is configured to extract from the target portion heat that is generated via absorption of the radiation, wherein heat extraction of the cooling device is controlled based on measurements of cooling of the clamp.
4. The device of claim 3, wherein the measurements of cooling of the clamp comprise measurement of
20 a cooling water temperature gradient and mass-flow rate.
5. The device of any of claims 1-4, wherein a component comprises device cooling device heat shield, arranged to shield at least part of the cooling device from the wafer stage.
- 25 6. The device of any of claims 1-5, wherein a component comprises a heat shield.
7. The device of any of claims 1-6, wherein a component comprises a metrology frame.
8. A lithographic apparatus comprising the device according to any of claims 1-7.
30
9. The lithographic apparatus of claim 8, wherein the lithographic apparatus is operable to control the projection optics to adjust the patterned beam of radiation to compensate for substrate deformation using a model based on the heat extraction of the cooling device.
- 35 10. The lithographic apparatus of any of claims 8-9, further comprising a wafer pre-aligner operable to orient and thermally condition the wafer before transfer to the clamp and wherein the thermal control

system is operative to maintain a fourth temperature of the wafer pre-aligner at the common set-point magnitude.

11. The lithographic apparatus of any of claims 8-10, wherein in operational use of the lithographic apparatus a vacuum is maintained in the compartment.

12. A lithographic method comprising:

- projecting a patterned beam of radiation via projection optics onto a target portion of a semiconductor wafer held on a clamp at a wafer stage in a compartment of a lithographic apparatus, wherein the lithographic apparatus comprises:
- a first component having a first surface facing a first portion of a route within the compartment; and
- a second component having a second surface facing a second portion of the route within the compartment;
- conveying the wafer stage along the route within the compartment; and
- operating a thermal control system to maintain a first temperature of the first surface and a second temperature of the second surface at a common set-point magnitude.

13. The lithographic method of claim 12, further comprising operating the thermal control system to maintain a third temperature of the clamp at the common set-point magnitude.

14. The lithographic method of claim 12 or claim 13, further comprising operating a cooling device positioned underneath the projection optics to extract from the target portion heat that is generated via absorption of the radiation, wherein heat extraction of the cooling device is controlled based on measurements of cooling of the clamp.

15. The lithographic method of claim 14, wherein the measurements of cooling of the clamp comprise measurement of a cooling water temperature gradient and mass-flow rate.

16. The lithographic method of claim 14 or claim 15, comprising controlling the projection system to adjust the patterned beam of radiation to compensate for substrate deformation using a model based on the heat extraction of the cooling device.

17. The lithographic method of any of claims 12 to 16, further comprising to orienting and thermally conditioning the wafer using a wafer pre-aligner before transfer to the clamp and operating the thermal control system to maintain a fourth temperature of the wafer pre-aligner at the common set-point magnitude.

18. The lithographic method of any of claims 12 to 17, further comprising maintaining a vacuum in the compartment.

19. The lithographic method of any of claims 12 to 18, wherein a component comprises device cooling
5 device heat shield, arranged to shield at least part of the cooling device from the wafer stage.

20. The lithographic method of any of claims 12 to 19, wherein a component comprises a heat shield.

21. The lithographic method of any of claims 12 to 20, wherein a component comprises a metrology
10 frame.

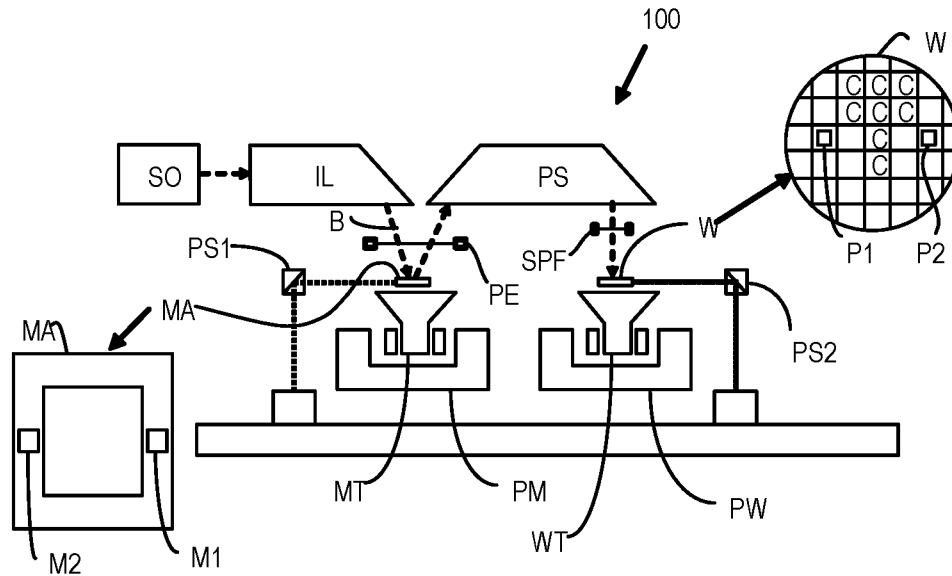


Fig. 1

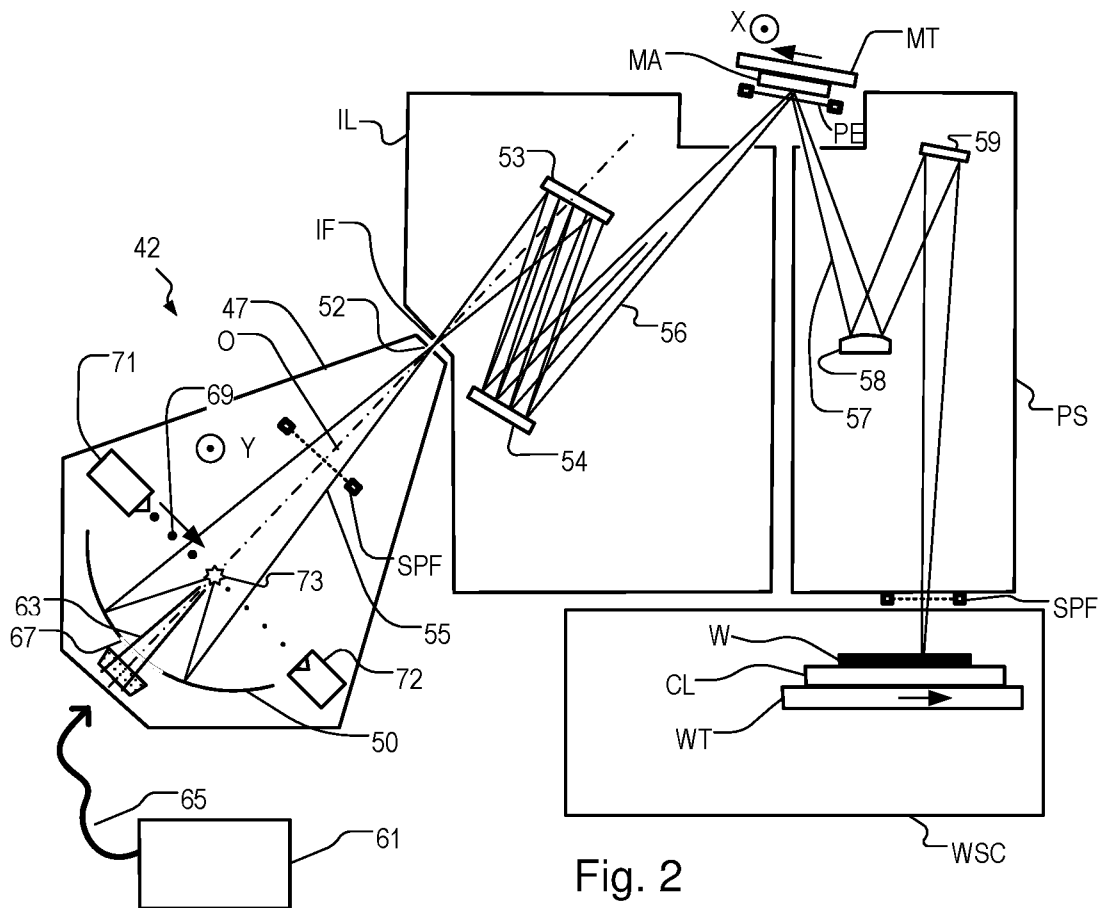


Fig. 2

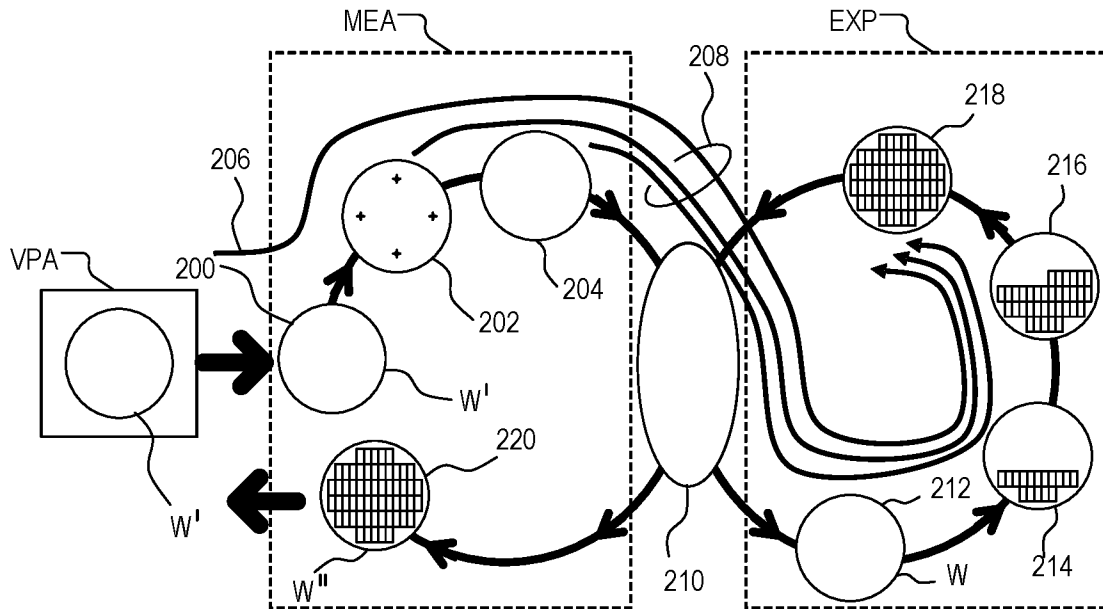


Fig. 3

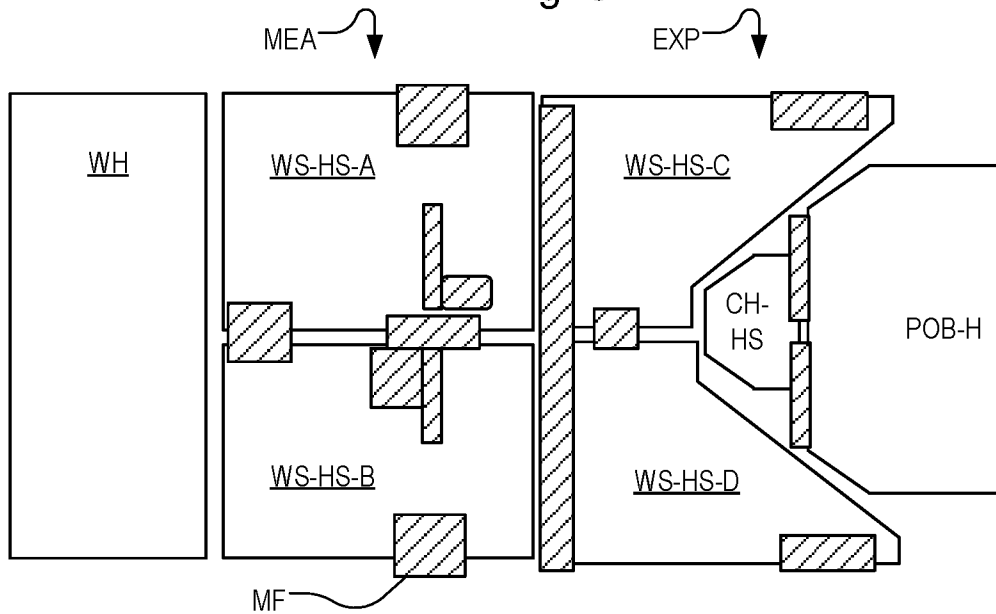


Fig. 4

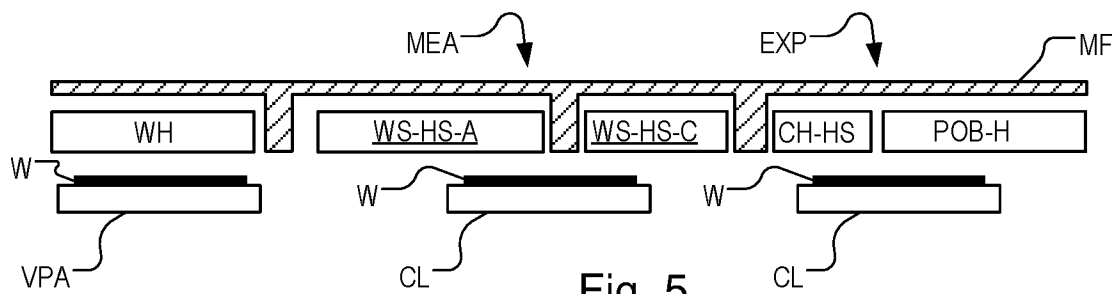


Fig. 5

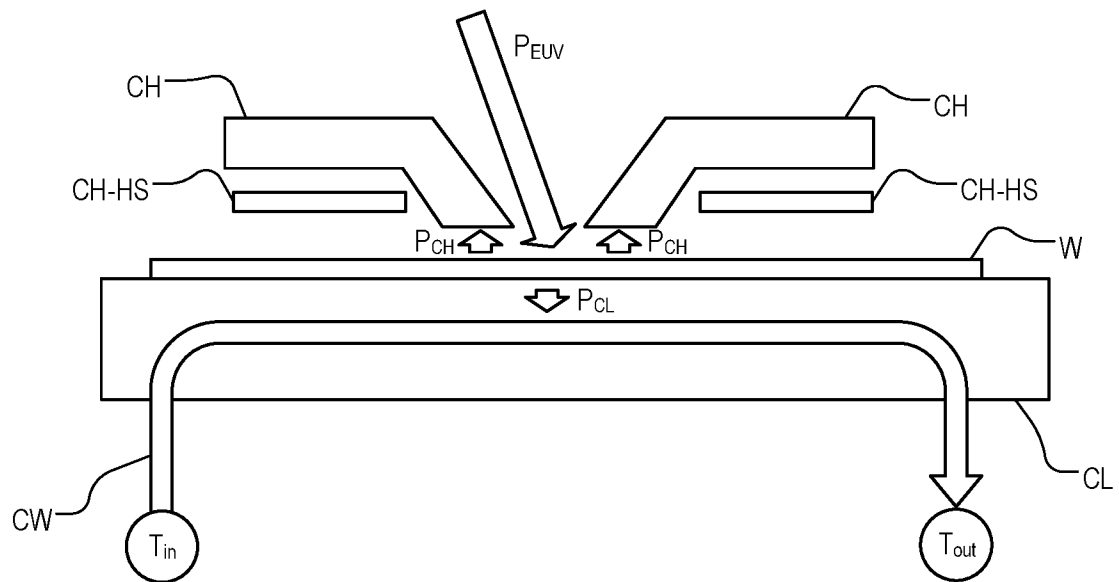


Fig. 6

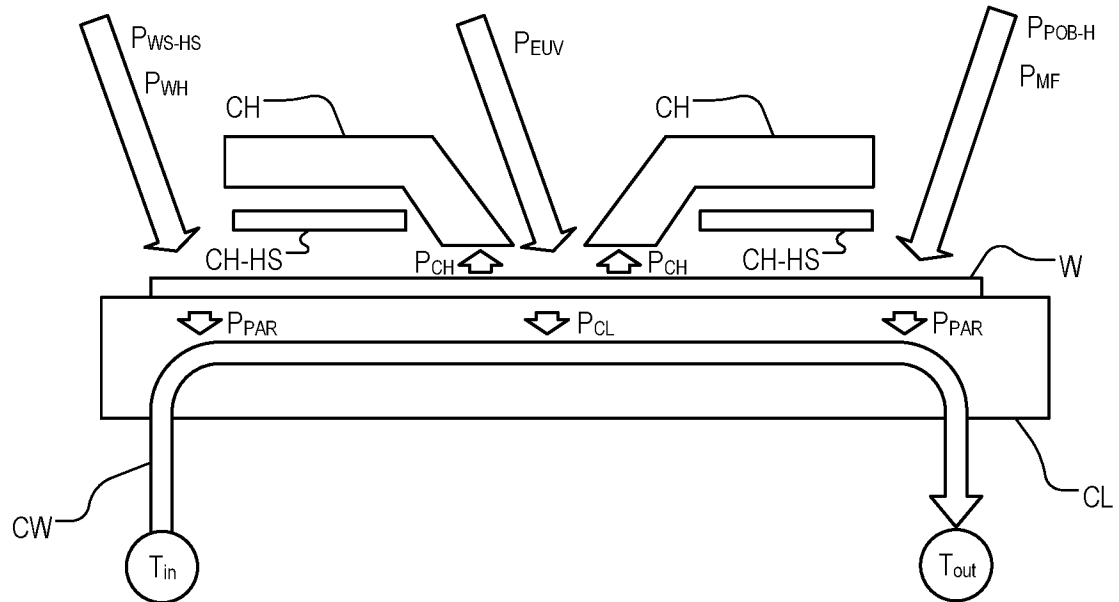


Fig. 7

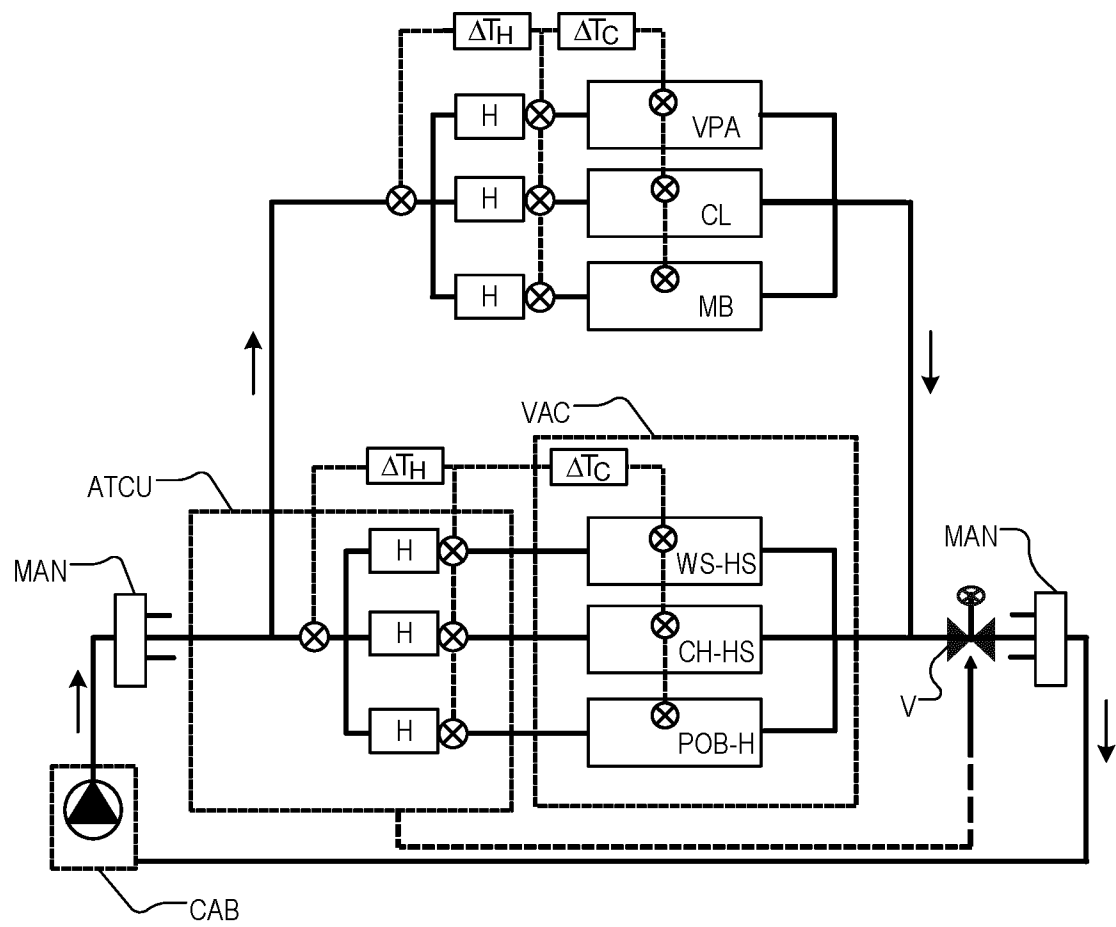


Fig. 8

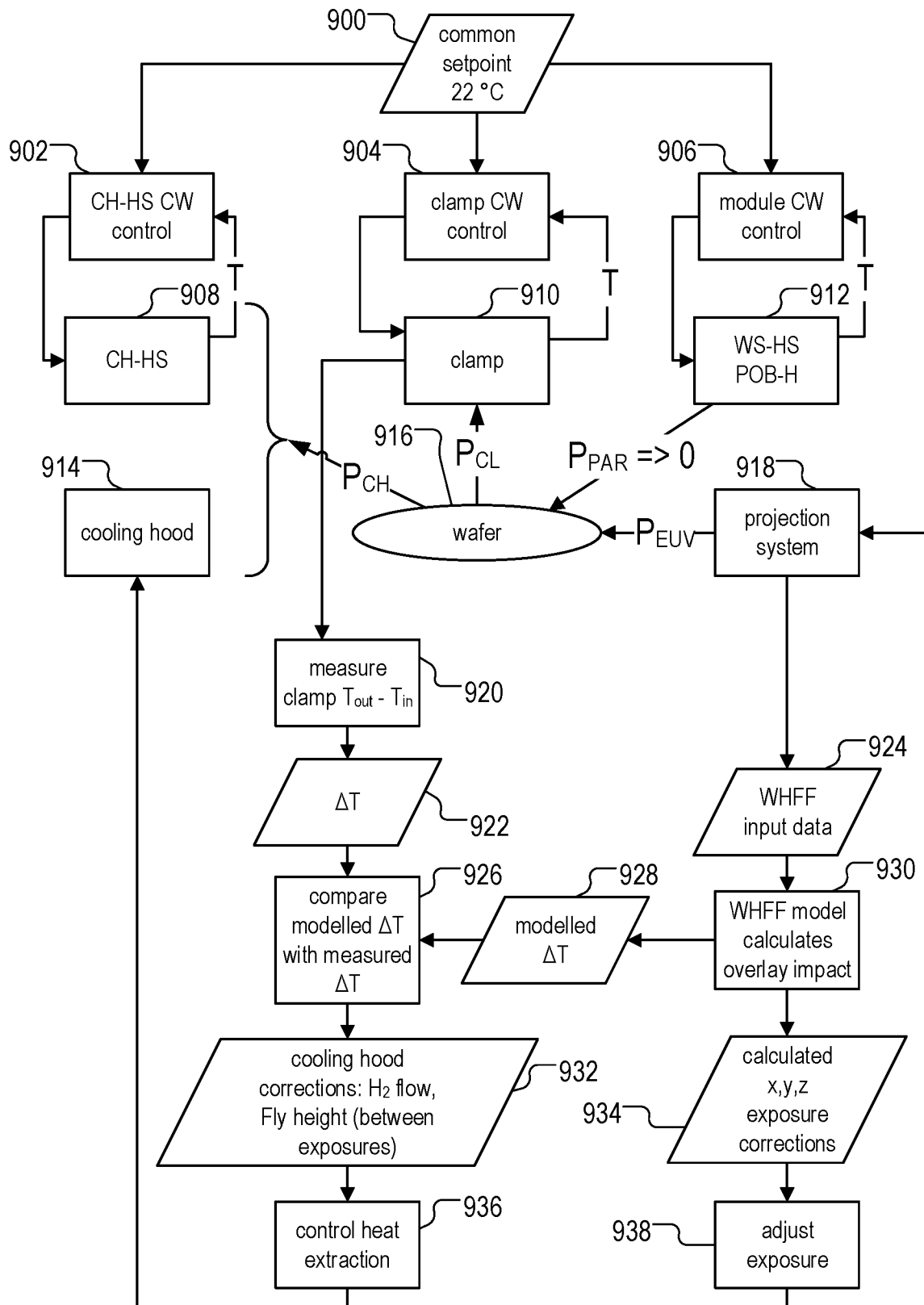


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/051355

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 531 364 A2 (ASML NETHERLANDS BV [NL]) 18 May 2005 (2005-05-18)	1,7,8, 10-12, 17,18,21
Y	paragraph [0029] - paragraph [0047] figures 1-5	2-6,9, 13-16, 19,20
Y	----- US 2005/146695 A1 (KAWAKAMI EIGO [JP]) 7 July 2005 (2005-07-07)	2,13
A	paragraph [0038] - paragraph [0047] figure 6	1,12
Y	----- US 2012/013865 A1 (LAURENT THIBAUT SIMON MATHIEU [NL] ET AL) 19 January 2012 (2012-01-19)	3,4,14, 15
A	paragraph [0103] - paragraph [0173] figure 11	1,12
	----- -/-	



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

14 May 2020

Date of mailing of the international search report

26/05/2020

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

Meixner, Matthias

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2020/051355

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2017/060259 A1 (ASML HOLDING NV [NL]; ASML NETHERLANDS BV [NL]) 13 April 2017 (2017-04-13)	5,6,19, 20
A	paragraph [0131] - paragraph [0133] figure 16	1,12
Y	----- EP 1 628 330 A1 (NIKON CORP [JP]) 22 February 2006 (2006-02-22)	9,16
A	paragraph [0059] - paragraph [0064] figure 4	1,12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/051355

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
EP 1531364	A2	18-05-2005	CN	1617048 A		18-05-2005
			EP	1531364 A2		18-05-2005
			JP	4452160 B2		21-04-2010
			JP	4900970 B2		21-03-2012
			JP	5619699 B2		05-11-2014
			JP	2005150732 A		09-06-2005
			JP	2009016868 A		22-01-2009
			JP	2012028797 A		09-02-2012
			KR	20050046626 A		18-05-2005
			SG	112064 A1		29-06-2005
			TW	I251131 B		11-03-2006
			US	2005105070 A1		19-05-2005
			US	2005151954 A1		14-07-2005

US 2005146695	A1	07-07-2005	JP	4371822 B2		25-11-2009
			JP	2005197384 A		21-07-2005
			US	2005146695 A1		07-07-2005
			US	2008186463 A1		07-08-2008

US 2012013865	A1	19-01-2012	JP	5373001 B2		18-12-2013
			JP	2012023371 A		02-02-2012
			US	2012013865 A1		19-01-2012
			US	2016202618 A1		14-07-2016
			US	2018074411 A1		15-03-2018
			US	2019171113 A1		06-06-2019

WO 2017060259	A1	13-04-2017	CN	108139684 A		08-06-2018
			CN	110716396 A		21-01-2020
			JP	2018531410 A		25-10-2018
			KR	20180059936 A		05-06-2018
			KR	20190126450 A		11-11-2019
			NL	2017576 A		11-04-2017
			TW	201723676 A		01-07-2017
			TW	202006478 A		01-02-2020
			US	2018321602 A1		08-11-2018
			WO	2017060259 A1		13-04-2017

EP 1628330	A1	22-02-2006	CN	1795535 A		28-06-2006
			CN	101614966 A		30-12-2009
			EP	1628330 A1		22-02-2006
			EP	2453465 A2		16-05-2012
			JP	5218471 B2		26-06-2013
			JP	5218517 B2		26-06-2013
			JP	5218518 B2		26-06-2013
			JP	5541308 B2		09-07-2014
			JP	5668835 B2		12-02-2015
			JP	2010199615 A		09-09-2010
			JP	2011018942 A		27-01-2011
			JP	2011044725 A		03-03-2011
			JP	2012129558 A		05-07-2012
			JP	2014057112 A		27-03-2014
			KR	20060009956 A		01-02-2006
			KR	20110110320 A		06-10-2011
			KR	20120064138 A		18-06-2012
			KR	20130023401 A		07-03-2013
			KR	20130023402 A		07-03-2013
			KR	20150036794 A		07-04-2015
			KR	20170043676 A		21-04-2017

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/051355

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		KR 20180122033 A	09-11-2018
		TW I374339 B	11-10-2012
		TW 201243519 A	01-11-2012
		TW 201530266 A	01-08-2015
		TW 201721300 A	16-06-2017
		TW 201833690 A	16-09-2018
		US 2006082744 A1	20-04-2006
		US 2006098179 A1	11-05-2006
		US 2008309896 A1	18-12-2008
		US 2009104568 A1	23-04-2009
		US 2013182232 A1	18-07-2013
		US 2017003599 A1	05-01-2017
		US 2019011840 A1	10-01-2019
		WO 2004107417 A1	09-12-2004
