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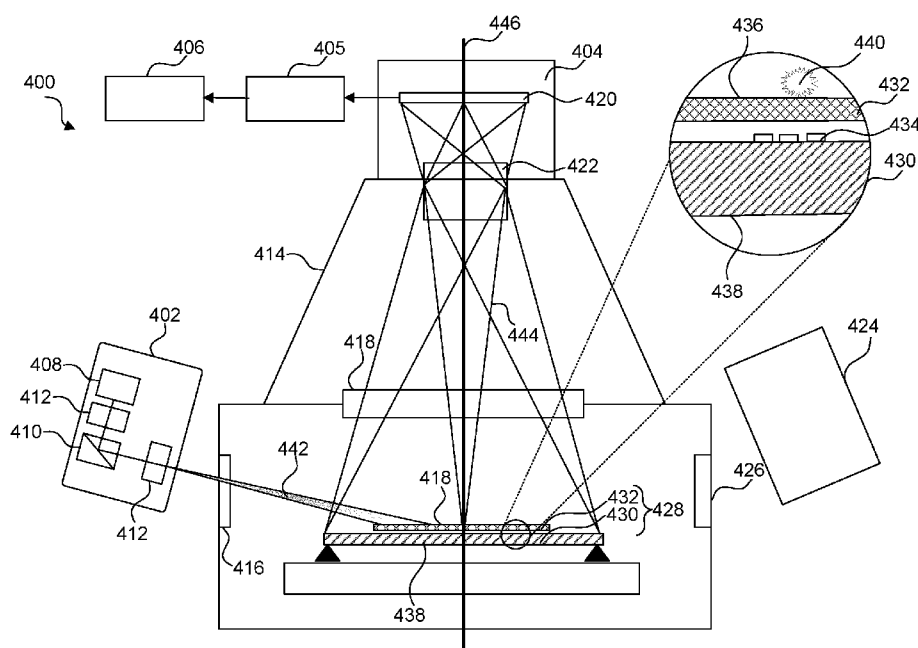


FIG. 4

(57) Abstract: A system can include a light source configured to illuminate a surface of a pellicle, a scanner configured to scan the surface of the pellicle; a spectrometer configured to measure a Raman spectra of a reference signal and a test signal, the reference signal being based on a measurement from a surface of the pellicle and/or a reticle and the test signal being based on the illuminated surface of the pellicle, and a processor. The processor can be configured to determine a difference between the Raman spectra of the reference signal and the test signal and identify a presence of a contaminant on the surface of the pellicle in response to detecting a deviation in the Raman spectra of the reference signal and the test signal.



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CONTAMINANT-DETECTING SYSTEM AND METHOD

FIELD

5 [0001] The present disclosure relates to lithographic systems, for example, inspection systems for detecting contaminants on a pellicle in a lithographic apparatus.

BACKGROUND

10 [0002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, can 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
15 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. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the “scanning”-
20 direction) while synchronously scanning the target portions parallel or anti-parallel to this scanning direction. It is also possible to transfer the pattern from the patterning device to the substrate by imprinting the pattern onto the substrate.

[0003] Another lithographic system is an interferometric lithographic system where there is no patterning device, but rather a light beam is split into two beams, and the two beams are caused to
25 interfere at a target portion of the substrate through the use of a reflection system. The interference causes lines to be formed at the target portion of the substrate.

[0004] During lithographic operation, different processing steps may require different layers to be sequentially formed on the substrate. Sequencing of layers is typically accomplished by exchanging different reticles, according to the desired pattern for each layer, for each pattern transfer process. A
30 typical lithographic system works within sub-nanometer tolerances regarding patterns on the reticle and patterns transferred onto the wafer from the reticle. A contaminant particle on a reticle may introduce errors to transferred patterns. Therefore, it is desirable to maintain contaminant-free reticles capable of accurately transferring patterns onto wafers with sub-nanometer accuracy.

[0005] Within the environment of the lithographic apparatus, highly dynamic processes take place,
35 e.g., reticle hand-off, wafer hand-off, controlled gas flows, outgassing of vacuum chamber walls, liquid dispensing (e.g., photoresist coating), temperature variations, metal deposition, rapid movement of

numerous actuatable components, and wear of structures. Over time, dynamic processes introduce and build up contaminant particles within the lithographic apparatus.

SUMMARY

5 [0006] There is a need to provide improved inspection techniques to detect contaminants on optically critical components of a lithographic apparatus.

[0007] In some embodiments, a method includes the following operations. Measuring a first value associated with a pellicle and/or a reticle surface. Illuminating the pellicle surface. Measuring a second value associated with the illuminated pellicle surface. Determining a difference between a Raman spectra of the first and second values. Identifying a presence of a contaminant on the pellicle surface in response to the determining.

10 [0008] In some embodiments, a system includes the following components. A light source configured to illuminate a surface of a pellicle; a scanner configured to scan the surface of the pellicle. A spectrometer configured to measure a Raman spectra of a reference signal and a test signal, the reference signal being based on a measurement from a surface of the pellicle and/or a reticle and the test signal being based on the illuminated surface of the pellicle. A processor configured to determine a difference between the Raman spectra of the reference signal and the test signal and identify a presence of a contaminant on the surface of the pellicle in response to detecting a deviation in the Raman spectra of the reference signal and the test signal.

15 [0009] In some embodiments, a non-transitory computer readable medium storing one or more sequences of one or more instructions for execution by one or more processors to perform operations. Measuring a first value associated with a pellicle and/or a reticle surface. Illuminating the pellicle surface. Measuring a second value associated with the illuminated pellicle surface. Determining a difference between a Raman spectra of the first and second values. Identifying a presence of a contaminant on the pellicle surface in response to the determining.

20 [0010] Further features of the present disclosure, as well as the structure and operation of various embodiments, are described in detail below with reference to the accompanying drawings. It is noted that the present disclosure is not limited to the specific embodiments described herein. Such embodiments are presented herein for illustrative purposes only. Additional embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

30 [0011] The accompanying drawings, which are incorporated herein and form part of the specification, illustrate the present disclosure and, together with the description, further serve to explain the principles of the present disclosure and to enable a person skilled in the relevant art(s) to make and use embodiments described herein.

[0012] FIG. 1A shows a schematic of a reflective lithographic apparatus, according to some embodiments.

[0013] FIG. 1B shows a schematic of a transmissive lithographic apparatus, according to some embodiments.

5 [0014] FIG. 2 shows a more detailed schematic of the reflective lithographic apparatus, according to some embodiments.

[0015] FIG. 3 shows a schematic of a lithographic cell, according to some embodiments.

[0016] FIGS. 4 and 5 show schematics of metrology systems, according to some embodiments.

10 [0017] The features of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. Additionally, generally, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears. Unless otherwise indicated, the drawings provided throughout the disclosure should not be interpreted
15 as to-scale drawings.

DETAILED DESCRIPTION

[0018] This specification discloses one or more embodiments that incorporate the features of the present disclosure. The disclosed embodiment(s) are provided as examples. The scope of the present
20 disclosure is not limited to the disclosed embodiment(s). Claimed features are defined by the claims appended hereto.

[0019] The embodiment(s) described, and references in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment(s) described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the
25 particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is understood that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

30 [0020] Spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “on,” “upper” and the like, can be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus can be otherwise oriented (rotated 90 degrees or at other orientations) and
35 the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0021] The term “about” as used herein indicates the value of a given quantity that can vary based on a particular technology. Based on the particular technology, the term “about” can indicate a value of a

given quantity that varies within, for example, 10–30% of the value (e.g., $\pm 10\%$, $\pm 20\%$, or $\pm 30\%$ of the value).

[0022] Embodiments of the disclosure can be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the disclosure may also be implemented as instructions stored on a machine-readable medium, which can be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, and/or instructions can be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact result from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc. The term “non-transitory” may be used herein to characterize computer readable media used for storing data, information, instructions, and the like, with the sole exception being a transitory, propagating signal.

[0023] Before describing such embodiments in more detail, however, it is instructive to present an example environment in which embodiments of the present disclosure can be implemented.

[0024] Example Lithographic Systems

[0025] FIGS. 1A and 1B show schematic illustrations of a lithographic apparatus 100 and lithographic apparatus 100', respectively, in which embodiments of the present disclosure may be implemented. Lithographic apparatus 100 and lithographic apparatus 100' each include the following: an illumination system (illuminator) IL configured to condition a radiation beam B (for example, deep ultra violet or extreme ultra violet radiation); a support structure (for example, a mask table) MT configured to support a patterning device (for example, a mask, a reticle, or a dynamic patterning device) MA and connected to a first positioner PM configured to accurately position the patterning device MA; and, a substrate table (for example, a wafer table) WT configured to hold a substrate (for example, a resist coated wafer) W and connected to a second positioner PW configured to accurately position the substrate W. Lithographic apparatus 100 and 100' also have a projection system PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion (for example, comprising one or more dies) C of the substrate W. In lithographic apparatus 100, the patterning device MA and the projection system PS are reflective. In lithographic apparatus 100', the patterning device MA and the projection system PS are transmissive.

[0026] The illumination system IL may include various types of optical components, such as refractive, reflective, catadioptric, magnetic, electromagnetic, electrostatic, or other types of optical components, or any combination thereof, for directing, shaping, or controlling the radiation beam B.

[0027] The support structure MT holds the patterning device MA in a manner that depends on the orientation of the patterning device MA with respect to a reference frame, the design of at least one of the lithographic apparatus 100 and 100', and other conditions, such as whether or not the patterning device MA is held in a vacuum environment. The support structure MT may use mechanical, vacuum, electrostatic, or other clamping techniques to hold the patterning device MA. The support structure MT may be a frame or a table, for example, which may be fixed or movable, as required. By using sensors, the support structure MT may ensure that the patterning device MA is at a desired position, for example, with respect to the projection system PS.

[0028] The term "patterning device" MA should be broadly interpreted as referring to any device that may be used to impart a radiation beam B with a pattern in its cross-section, such as to create a pattern in the target portion C of the substrate W. The pattern imparted to the radiation beam B may correspond to a particular functional layer in a device being created in the target portion C to form an integrated circuit.

[0029] The patterning device MA may be transmissive (as in lithographic apparatus 100' of FIG. 1B) or reflective (as in lithographic apparatus 100 of FIG. 1A). Examples of patterning devices MA include reticles, masks, programmable mirror arrays, or programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase shift, or 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 may be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in the radiation beam B, which is reflected by a matrix of small mirrors.

[0030] The term "projection system" PS may encompass any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors, such as the use of an immersion liquid on the substrate W or the use of a vacuum. A vacuum environment may be used for EUV or electron beam radiation since other gases may absorb too much radiation or electrons. A vacuum environment may therefore be provided to the whole beam path with the aid of a vacuum wall and vacuum pumps.

[0031] Lithographic apparatus 100 and/or lithographic apparatus 100' may be of a type having two (dual stage) or more substrate tables WT (and/or two or more mask tables). In such "multiple stage" machines, the additional substrate tables WT may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other substrate tables WT are being used for exposure. In some situations, the additional table may not be a substrate table WT.

[0032] The lithographic apparatus may also be of a type wherein at least a portion of the substrate may be covered by a liquid having a relatively high refractive index, e.g., water, so as to fill a space between the projection system and the substrate. An immersion liquid may also be applied to other spaces in the lithographic apparatus, for example, between the mask and the projection system. Immersion techniques

are well known in the art for increasing the numerical aperture of projection systems. The term “immersion” as used herein does not mean that a structure, such as a substrate, must be submerged in liquid, but rather only means that liquid is located between the projection system and the substrate during exposure.

5 [0033] Referring to FIGS. 1A and 1B, the illuminator IL receives a radiation beam from a radiation source SO. The source SO and the lithographic apparatus 100, 100' may be separate physical entities, for example, when the source SO is an excimer laser. In such cases, the source SO is not considered to form part of the lithographic apparatus 100 or 100', and the radiation beam B passes from the source SO to the illuminator IL with the aid of a beam delivery system BD (in FIG. 1B) including, for example,
10 suitable directing mirrors and/or a beam expander. In other cases, the source SO may be an integral part of the lithographic apparatus 100, 100', for example, when the source SO is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD, if required, may be referred to as a radiation system.

[0034] The illuminator IL may include an adjuster AD (in FIG. 1B) for adjusting the angular intensity
15 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 may be adjusted. In addition, the illuminator IL may comprise various other components (in FIG. 1B), such as an integrator IN and a condenser CO. The illuminator IL may be used to condition the radiation beam B to have a desired uniformity and intensity distribution in its cross section.

20 [0035] Referring to FIG. 1A, the radiation beam B is incident on the patterning device (for example, mask) MA, which is held on the support structure (for example, mask table) MT, and is patterned by the patterning device MA. In lithographic apparatus 100, the radiation beam B is reflected from the patterning device (for example, mask) MA. After being reflected from the patterning device (for example, mask) MA, the radiation beam B passes through the projection system PS, which focuses the
25 radiation beam B onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF2 (for example, an interferometric device, linear encoder, or capacitive sensor), the substrate table WT may be moved accurately (for example, 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 IF1 may be used to accurately position the patterning device (for example, mask) MA with respect to
30 the path of the radiation beam B. Patterning device (for example, mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

[0036] Referring to FIG. 1B, the radiation beam B is incident on the patterning device (for example, mask MA), which is held on the support structure (for example, mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the
35 projection system PS, which focuses the beam onto a target portion C of the substrate W. The projection system has a pupil conjugate PPU to an illumination system pupil IPU. Portions of radiation emanate from the intensity distribution at the illumination system pupil IPU and traverse a mask pattern without

being affected by diffraction at the mask pattern and create an image of the intensity distribution at the illumination system pupil IPU.

[0037] The projection system PS projects an image MP' of the mask pattern MP, where image MP' is formed by diffracted beams produced from the mark pattern MP by radiation from the intensity distribution, onto a photoresist layer coated on the substrate W. For example, the mask pattern MP may include an array of lines and spaces. A diffraction of radiation at the array and different from zeroth order diffraction generates diverted diffracted beams with a change of direction in a direction perpendicular to the lines. Undiffracted beams (i.e., so-called zeroth order diffracted beams) traverse the pattern without any change in propagation direction. The zeroth order diffracted beams traverse an upper lens or upper lens group of the projection system PS, upstream of the pupil conjugate PPU of the projection system PS, to reach the pupil conjugate PPU. The portion of the intensity distribution in the plane of the pupil conjugate PPU and associated with the zeroth order diffracted beams is an image of the intensity distribution in the illumination system pupil IPU of the illumination system IL. The aperture device PD, for example, is disposed at or substantially at a plane that includes the pupil conjugate PPU of the projection system PS.

[0038] The projection system PS is arranged to capture, by means of a lens or lens group L, not only the zeroth order diffracted beams, but also first-order or first- and higher-order diffracted beams (not shown). In some embodiments, dipole illumination for imaging line patterns extending in a direction perpendicular to a line may be used to utilize the resolution enhancement effect of dipole illumination. For example, first-order diffracted beams interfere with corresponding zeroth-order diffracted beams at the level of the wafer W to create an image of the line pattern MP at highest possible resolution and process window (i.e., usable depth of focus in combination with tolerable exposure dose deviations). In some embodiments, astigmatism aberration may be reduced by providing radiation poles (not shown) in opposite quadrants of the illumination system pupil IPU. Further, in some embodiments, astigmatism aberration may be reduced by blocking the zeroth order beams in the pupil conjugate PPU of the projection system associated with radiation poles in opposite quadrants. This is described in more detail in US 7,511,799 B2, issued Mar. 31, 2009, which is incorporated by reference herein in its entirety.

[0039] With the aid of the second positioner PW and position sensor IF (for example, an interferometric device, linear encoder, or capacitive sensor), the substrate table WT may be moved accurately (for example, 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 (not shown in FIG. 1B) may be used to accurately position the mask MA with respect to the path of the radiation beam B (for example, after mechanical retrieval from a mask library or during a scan).

[0040] In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper

(as opposed to a scanner), the mask table MT may be connected to a short-stroke actuator only or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2, and substrate alignment marks P1, P2. Although the substrate alignment marks (as illustrated) occupy dedicated target portions, they may be located in spaces between target portions (known as scribe-lane alignment marks).

5 Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

[0041] Mask table MT and patterning device MA may be in a vacuum chamber V, where an in-vacuum robot IVR may be used to move patterning devices such as a mask in and out of vacuum chamber. Alternatively, when mask table MT and patterning device MA are outside of the vacuum chamber, an
10 out-of-vacuum robot may be used for various transportation operations, similar to the in-vacuum robot IVR. Both the in-vacuum and out-of-vacuum robots need to be calibrated for a smooth transfer of any payload (e.g., mask) to a fixed kinematic mount of a transfer station.

[0042] The lithographic apparatus 100 and 100' may be used in at least one of the following modes:

1. In step mode, the support structure (for example, mask table) MT and the substrate
15 table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam B is projected onto a target portion C at one time (i.e., a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C may be exposed.

2. In scan mode, the support structure (for example, mask table) MT and the substrate
20 table WT are scanned synchronously while a pattern imparted to the radiation beam B is projected onto a target portion C (i.e., a single dynamic exposure). The velocity and direction of the substrate table WT relative to the support structure (for example, mask table) MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS.

3. In another mode, the support structure (for example, mask table) MT is kept
25 substantially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam B is projected onto a target portion C. A pulsed radiation source SO may be employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation may be readily applied to maskless lithography that utilizes a programmable patterning device, such as a programmable mirror array.

30 [0043] Combinations and/or variations on the described modes of use or entirely different modes of use may also be employed.

[0044] In some embodiments, a lithographic apparatus may generate DUV and/or EUV radiation. For example, lithographic apparatus 100' may be configured to operate using a DUV source. In another example, lithographic apparatus 100 includes an extreme ultraviolet (EUV) source, which is configured
35 to generate a beam of EUV radiation for EUV lithography. In general, the EUV source is configured in a radiation system, and a corresponding illumination system is configured to condition the EUV radiation beam of the EUV source.

[0045] FIG. 2 shows the lithographic apparatus 100 in more detail, including the source collector apparatus SO, the illumination system IL, and the projection system PS. The source collector apparatus SO is constructed and arranged such that a vacuum environment may be maintained in an enclosing structure 220 of the source collector apparatus SO. An EUV radiation emitting plasma 210 may be formed by a discharge produced plasma source. EUV radiation may be produced by a gas or vapor, for example Xe gas, Li vapor, or Sn vapor in which the very hot plasma 210 is created to emit radiation in the EUV range of the electromagnetic spectrum. The very hot plasma 210 is created by, for example, an electrical discharge causing at least a partially ionized plasma. Partial pressures of, for example, 10 Pa of Xe, Li, Sn vapor, or any other suitable gas or vapor may be required for efficient generation of the radiation. In some embodiments, a plasma of excited tin (Sn) is provided to produce EUV radiation.

[0046] The radiation emitted by the hot plasma 210 is passed from a source chamber 211 into a collector chamber 212 via an optional gas barrier or contaminant trap 230 (in some cases also referred to as contaminant barrier or foil trap), which is positioned in or behind an opening in source chamber 211. The contaminant trap 230 may include a channel structure. Contamination trap 230 may also include a gas barrier or a combination of a gas barrier and a channel structure. The contaminant trap or contaminant barrier 230 further indicated herein at least includes a channel structure.

[0047] The collector chamber 212 may include a radiation collector CO, which may be a so-called grazing incidence collector. Radiation collector CO has an upstream radiation collector side 251 and a downstream radiation collector side 252. Radiation that traverses collector CO may be reflected off a grating spectral filter 240 to be focused in a virtual source point IF. The virtual source point IF is commonly referred to as the intermediate focus, and the source collector apparatus is arranged such that the intermediate focus IF is located at or near an opening 219 in the enclosing structure 220. The virtual source point IF is an image of the radiation emitting plasma 210. Grating spectral filter 240 is used in particular for suppressing infra-red (IR) radiation.

[0048] Subsequently the radiation traverses the illumination system IL, which may include a faceted field mirror device 222 and a faceted pupil mirror device 224 arranged to provide a desired angular distribution of the radiation beam 221, at the patterning device MA, as well as a desired uniformity of radiation intensity at the patterning device MA. Upon reflection of the beam of radiation 221 at the patterning device MA, held by the support structure MT, a patterned beam 226 is formed and the patterned beam 226 is imaged by the projection system PS via reflective elements 228, 229 onto a substrate W held by the wafer stage or substrate table WT.

[0049] More elements than shown may generally be present in illumination optics unit IL and projection system PS. The grating spectral filter 240 may optionally be present, depending upon the type of lithographic apparatus. Further, there may be more mirrors present than those shown in the FIG. 2, for example there may be one to six additional reflective elements present in the projection system PS than shown in FIG. 2.

[0050] Collector optic CO, as illustrated in FIG. 2, is depicted as a nested collector with grazing incidence reflectors 253, 254, and 255, just as an example of a collector (or collector mirror). The grazing incidence reflectors 253, 254, and 255 are disposed axially symmetric around an optical axis O and a collector optic CO of this type is preferably used in combination with a discharge produced plasma source, often called a DPP source.

[0051] Exemplary Lithographic Cell

[0052] FIG. 3 shows a lithographic cell 300, also sometimes referred to a lithocell or cluster, according to some embodiments. Lithographic apparatus 100 or 100' may form part of lithographic cell 300. Lithographic cell 300 may also include one or more apparatuses to perform pre- and post-exposure processes on a substrate. Conventionally these include spin coaters SC to deposit resist layers, developers DE to develop exposed resist, chill plates CH, and bake plates BK. A substrate handler, or robot, RO picks up substrates from input/output ports I/O1, I/O2, moves them between the different process apparatuses and delivers them to the loading bay LB of the lithographic apparatus 100 or 100'. These devices, which are often collectively referred to as the track, are under the control of a track control unit TCU, which is itself controlled by a supervisory control system SCS, which also controls the lithographic apparatus via lithography control unit LACU. Thus, the different apparatuses may be operated to maximize throughput and processing efficiency.

[0053] Exemplary Contaminant Inspection Apparatus

[0054] In some embodiments, a metrology system may be used to inspect an object in order to determine a cleanliness of the object. Inspection techniques may be performed such that undesirable defects on a surface (e.g., a surface of a reticle or substrate) are successfully detected while minimizing false detections (or false positives). Inspection techniques may comprise chemical inspection, optical inspection, or a combination of both.

[0055] The term "imperfection," "defect," "blemish," and the like may be used herein to refer to deviations or non-uniformities of structures from a specified tolerance. For example, a flat surface may have defects such as scratches, holes, or recesses, foreign particles, stains, and the like.

[0056] In the context of imperfections, the terms "foreign particle," "contaminant particle," "contaminant," and the like may be used herein to refer to unexpected, atypical, undesirable, or the like (herein undesirable) particulate matter that is present in a region or on a surface that was not designed to tolerate the presence of the undesirable particulate matter or otherwise adversely impacts operation of the apparatus on which the particulate matter is present. Such "foreign particles" and "contaminants" may include, but are not limited to, organic materials, such as human tissue/cells, inorganic contaminants, such as metal/alloy shavings. Organic contaminants may be the result of how parts/modules are handled during production, shipping, and assembly. The inorganic contaminants may be the result of technological processes used to manufacture the parts/modules. For example, parts/modules may be processed on lathes or milling machines, thereby generating a large number of small particles on the parts/modules that, even with multiple subsequent cleaning steps, may still be

found on tested surfaces. Some examples of inorganic contaminants may include dust, stray photoresist, or other dislodged materials within the lithographic apparatus. Examples of dislodged materials may include steel, Au, Ag, Al, Cu, Pd, Pt, Ti, and the like. Material dislodging may occur due to, e.g., processes of fabricating metal interconnects on substrates and friction and impacts of actuated structures. Contaminants may make their way onto sensitive parts in the lithographic apparatus (e.g., reticle or substrate) and increase the likelihood of errors in lithographic processes. Embodiments of the present disclosure provide structures and functions for detecting defects on sensitive parts of a lithographic apparatus or process.

[0057] FIG. 4 shows a schematic of a metrology system 400, according to some embodiments. In some embodiments, metrology system 400 may be implemented in a lithographic apparatus, e.g., lithographic apparatus 100 and/or 100'. Metrology system 400 may comprise an illumination system 402, a detector 404, a spectrometer 405, and a processor 406. Illumination system 402 may comprise a radiation source 408 and a spatial light modulator 410. Illumination system 402 may comprise one or more radiation adjusting elements 412 (e.g., any of polarizers, wavelength filters, focusing elements, beam splitters, beam combiners, and the like). Metrology system 400 may comprise an enclosure 414. Enclosure 414 may comprise one or more compartments. Enclosure 414 may comprise viewport windows 416 and 418. Metrology system 400 may comprise one or more additional illumination systems 424. Illumination system 424 may be substantially similar to illumination system 402 in structure and function. Enclosure 414 may comprise one or more additional viewport windows 426.

[0058] In some embodiments, detector 404 may comprise a plurality of sensor elements 420 and a focusing element 422 (e.g., an objective lens or lens system). In some embodiments, detector 404 may be a single-cell photo-detector (without more, may not be able to resolve an image), in which case sensor element 420 may be a photo-sensitive diode. In some embodiments, detector 404 may be a multi-cell photo-detector (e.g., two dimensional array of photo-detectors). Sensor element 420 may comprise a charge-coupled device (CCD) or a complementary metal-oxide-semiconductor (CMOS).

[0059] Processor 406 may be a comparator (e.g., a device that analyzes one or more pieces of information, quantities, or values for performing a comparison).

[0060] Before describing embodiments of metrology system 400 in more detail, however, it is instructive to present examples of an object 428 that may be inspected using metrology system 400. In some embodiments, object 428 may comprise a contiguous object or a multi-part object (FIG. 4 shows a magnified view of the multi-part variant). In embodiments where object 428 may have multiple parts, object 428 may be a reticle 430 having a pellicle 432 disposed on a side of reticle 430. Reticle 430 may comprise pattern features 434. Pattern features 434 may comprise, for example, product and alignment mark patterns to be transferred onto a substrate via a lithographic process. The quality of pattern transfer may be negatively impacted if a contaminant 440 is present on reticle 430, particularly on pattern features 434. Thus, pellicle 432 may be a transparent protector configured to prevent contaminant 440 from landing on the side of reticle 430 that hosts pattern features 434.

[0061] In some embodiments, object 428 may comprise a surface 436 and a surface 438. Surface 436 is disposed on a side of object 428 that is opposite of surface 438. Surface 436 may be configured to contact and prevent contaminant 440 from reaching pattern features 434 (e.g., contaminant 440 is shown disposed on surface 436). Surface 438 may be a backside surface (e.g., the non-feature side) of reticle 430. Object 428 may be arranged such that a gap exists between pellicle 432 and reticle 430. The gap may be in the range microns to millimeters. As a result of the distance between surface 436 and pattern features 434, contaminant 440 residing on surface 436 has a reduced likelihood of influencing a pattern transfer, since contaminant 440 may be out of focus with respect to the illumination used in a pattern transfer. However, it is still desirable to monitor surface 436 of pellicle 432 to prevent counts of foreign particles from reaching unacceptable levels. Conversely, a foreign particle on surface 438 of reticle 430 may also negatively impact lithography, since a foreign particle may print through or otherwise distort a shape of reticle 430 when the foreign particle is sandwiched between reticle 430 and a reticle table, or cause damage to the reticle or reticle table surfaces when sandwiched between them, or transfer to the reticle table and thus contaminate it and potentially contaminate or damage other reticles loaded on the same stage.

[0062] In some embodiments, radiation source 408 may generate a beam of radiation 442 to illuminate object 428. Beam of radiation 442 may comprise incoherent radiation. It should be appreciated that beam of radiation 442 may be sourced with a coherent source. Beam of radiation 442 may comprise a wavelength (e.g., a narrow bandwidth centered about a central wavelength). Beam of radiation 442 may comprise two or more wavelengths (e.g., multiple discrete narrow bands or a continuum). One or more radiation adjusting elements 412 (e.g., wavelength filters) may be used to select wavelengths to be used for illuminating object 428. Additionally or alternatively, radiation source 408 may comprise two or more discrete radiation sources to generate distinct portions of the two or more wavelengths.

[0063] In some embodiments, spatial light modulator 410 may direct beam of radiation 442 toward surface 436 of object 428. Spatial light modulator 410 may adjust a spatial intensity distribution of beam of radiation 442 at surface 436. That is, the illumination directed onto object 428 may be selectable at a pixel level, as opposed to, e.g., flood illumination. Spatial light modulator 410 may comprise a liquid crystal modulator. Spatial light modulator 410 may also comprise an illumination-directing element (e.g., a reflector) and/or polarizer. Liquid crystals may operate based on polarization of light. For example, a pixel element of a liquid crystal device may allow full transmission, partial transmission, or no transmission of radiation based on a polarization state of the liquid crystal pixel element.

[0064] In some embodiments, spatial light modulator 410 may comprise a digital micromirror device (DMD). DMDs may operate based on mechanically movable micromirrors that reflect light toward a desired location. In some embodiments, spatial light modulator 410 may employ optical elements (e.g., pixel elements) with spatially variable transmission profile capable of generating required intensity profile through projection/illumination system at the object plane. The may be, for example, chrome on glass patterns, photographic films with desirable transmission profiles, and the like.

[0065] In some embodiments, detector 404 may receive radiation, represented by detected radiation 444, scattered at surface 436 and by structures near the surface (e.g., pattern features 434). Detected radiation 444 scattered at surface 436 may include radiation scattered by contaminant 440 that is disposed on surface 436. Detector 404 may generate a detection signal based on the received radiation.

5 [0066] Spectrometer 405 may receive and analyze the detection signal. For example, spectrometer 405 may separate and measure spectral components, e.g., a Raman spectrum, of the detection signal. Spectrometer 405 may provide the Raman spectrum of the detection signal to processor 406. In turn, processor 406 may analyze the Raman spectrum of the detection signal to determine whether contaminant 440 is present on the object 428. For example, processor 406 may compare a current
10 Raman spectrum of the detection signal to a reference signal and determine whether contaminant 440 is present on object 428 based on such comparison.

[0067] To achieve this, processor 406 may measure a first value associated with object 428, e.g., pellicle 432 and/or reticle 430. For example, the first value may be based on a Raman spectrum of a reference signal taken from a surface of object 428. In some embodiments, spectrometer 405 may be
15 used to measure a Raman spectrum of the reference signal at a plurality of locations of object 428. Using these measurements, processor 406 may determine a 1-dimensional array (Nx1 array) for each location of the plurality locations, with N being the number of elements 420 of detector 404. Processor 406 may calculate a histogram for each of the elements 420 of detector 404 and perform a Gaussian fit on the histograms after removing any outliers. Processor 406 may then derive a mean value from the
20 Gaussian fit for the elements, wherein an array of mean values is used as the reference signal.

[0068] Lithographic apparatus 100 and/or 100' may be configured to scan a plurality of locations on the pellicle 432 during a scanning mode to search for contaminant 440. During the scanning mode, detector 404 may obtain a corresponding detection signal that is provided to spectrometer 405. In turn, for each location, spectrometer 405 may be used to receive and analyze the detection signal to measure
25 a second value associated with an illuminated surface of pellicle 432. For example, the surface of pellicle 432 may be illuminated using illumination system 402, and spectrometer 405 may measure a Raman spectrum of the detection signal at the given location.

[0069] Processor 406 may be configured to determine a difference between the Raman spectra of the first and second values. Based on a difference between the Raman spectra of the first and second values, processor 406 may identify a presence of contaminant 440 on the surface of pellicle 432. For example, to identify the presence of the contaminant 440, processor 406 may subtract the first value from the second value, and based on a difference between the first and second values, processor 406 may determine that contaminant 440 is present on the surface of pellicle 432. That is, when processor 406 detects a change between the first and second values, processor 406 may determine that contaminant
30 440 is present on the surface of pellicle 432. In this way, processor 406 may distinguish contaminant 440 from object 428 using a chemical composition analysis, rather than an optical analysis

[0070] Illumination system 402 may be configured to illuminate the surface of pellicle 432 using a plurality of colors (e.g., at a plurality of wavelengths), as should be understood by those of ordinary skill in the art. In some embodiments, for each color of the plurality of colors, processor 406 may be further configured to determine the difference between the Raman spectra of the first and second values and identify the presence of contaminant 440 accordingly.

[0071] In response to detecting contaminant 440 on the surface of pellicle 432, processor 406 may compare the difference between the Raman spectra of the first and second values to a database of known spectra of a plurality of contaminants. Based on such comparison, processor 406 may identify a contaminant type, e.g., an organic contaminant or an inorganic contaminant, as discussed herein.

[0072] Once processor 406 has identified the contaminant type, processor 406 may use this information to identify a source of contaminant 440. For example, in the event that contaminant 440 is an organic contaminant, processor 406 may determine that the source of contaminant 440 may be a result of how parts/modules are handled by an individual during production, shipping, and assembly. As another example, in the event that contaminant 440 is an inorganic contaminant, processor 406 may determine that the source of contaminant 440 may be the result of technological processes used to manufacture the parts/modules.

[0073] In response to determining the contaminant type, processor 406 may be used to identify a remediation process for removing contaminant 440. For example, some contaminants may require chemistry-based cleaning and/or etch cleaning, whereas other contaminants may require less invasive cleaning, as should be understood by those of ordinary skill in the art.

[0074] Although specific embodiments have been described in the context of detecting foreign particles (e.g., contaminant 440 (FIG. 4)), the embodiments described herein are not limited to particulate contamination detection. In some embodiments, the metrology systems described herein may detect imperfections in general such as scratches, holes, or recesses, foreign particles, stains, and the like. It is desirable to detect all types of imperfections that pose a risk of disrupting lithographic processes.

[0075] FIG. 5 shows a schematic of a metrology system 500, according to some embodiments. In some embodiments, metrology system 500 may comprises similar or identical components and configurations as metrology system 400, and as such, only differences the metrology systems are discussed herein. In some embodiments, detector 404 may also include a beam splitter, as should be understood by those of ordinary skill in the art. In some embodiments, metrology system 500 may also include an image sensor 507 is configured to receive the detection signal from detector 404 and capture an image of contaminant 440. In some embodiments, the image of contaminant 440 may be used by processor 406 in analyzing contaminant 440 to identify the contaminant type and/or by a technician to visually analyze contaminant 440.

[0076] In some embodiments, metrology systems 400, 500 described herein may be implemented in a larger system, for example, within a lithographic apparatus, e.g., a scanner.

[0077] Although specific reference can 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, 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 can be considered as synonymous with the more general terms “substrate” or “target portion”, respectively. The substrate referred to herein can be processed, before or after exposure, in for example a track unit (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology unit and/or an inspection unit. Where applicable, the disclosure herein can be applied to such and other substrate processing tools. Further, the substrate can 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 multiple processed layers.

[0078] Although specific reference may have been made above to the use of embodiments of the present disclosure in the context of optical lithography, it will be appreciated that the present disclosure can be used in other applications, for example imprint lithography, and where the context allows, is not limited to optical lithography. In imprint lithography a topography in a patterning device defines the pattern created on a substrate. The topography of the patterning device can be pressed into a layer of resist supplied to the substrate whereupon the resist is cured by applying electromagnetic radiation, heat, pressure or a combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

[0079] It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present disclosure is to be interpreted by those skilled in relevant art(s) in light of the teachings herein.

Other aspects of the invention are set out in the following numbered clauses.

1. A method, comprising:
measuring a first value associated with a pellicle and/or a reticle surface;
illuminating the pellicle surface;
measuring a second value associated with the illuminated pellicle surface;
determining a difference between a Raman spectra of the first and second values; and
identifying a presence of a contaminant on the pellicle surface in response to the determining.
2. The method of clause 1, further comprising identifying a contaminant type based on comparing the difference to a database of known spectra of a plurality of contaminants.
3. The method of clause 2, wherein the contaminant type comprises an organic contaminant or an inorganic contaminant.
4. The method of clause 2, further comprising identifying a contamination source based on the contaminant type.

5. The method of clause 2, further comprising identifying a remediation process for removing the contaminant based on the contaminant type.
6. The method of clause 1, wherein the determining the first value comprises:
using a detector comprising elements to measure a scattered signal at a plurality of locations of the
5 pellicle and/or the reticle surface;
calculating a histogram for each of the elements;
performing a Gaussian fit on the histogram after removing any outliers from the histogram; and
deriving mean values from the Gaussian fit for the elements, wherein the mean values is used as the first value.
- 10 7. The method of clause 6, wherein the mean values comprises a one dimensional array based on a number of the elements.
8. The method of clause 1, further comprising moving a detector to a plurality of locations on the pellicle during a scanning mode to scan the pellicle for contaminants at each of the plurality of locations.
9. The method of clause 1, further comprising capturing an image of the contaminant on the
15 pellicle surface.
10. The method of clause 1, wherein:
the illuminating the pellicle or the reticle surfaces comprises using a plurality of wavelengths, and
the measuring the first value, the determining, and the identifying are performed for each of the plurality of wavelengths.
- 20 11. A system, comprising:
a light source configured to illuminate a surface of a pellicle;
a scanner configured to scan the surface of the pellicle;
a spectrometer configured to measure a Raman spectrum of a test signal, the test signal being based on the illuminated surface of the pellicle; and
25 a processor configured to:
determine a difference between the Raman spectra of a reference signal and the test signal, the reference signal being based on a measurement from the surface of the pellicle and/or a reticle; and
identify a presence of a contaminant on the surface of the pellicle in response to detecting a deviation in the Raman spectra of the reference signal and the test signal.
- 30 12. The system of clause 12, wherein the processor is further configured to compare the deviation in the Raman spectra of the reference signal and the test signal to a database of known spectra of a plurality of contaminants.
13. The system of clause 13, wherein the processor is further configured to identify a contaminant type based on the comparison.
- 35 14. The system of clause 14, wherein the processor is further configured to identify a contamination source based on the contaminant type.

15. The system of clause 14, wherein the processor is further configured to identify a remediation process for removing the contaminant based on the contaminant type

16. The system of clause 12, wherein the scanner is further configured to scan a plurality of locations on the pellicle during the scanning mode to scan for contaminants at each of the plurality of
5 locations.

17. The system of clause 12, further comprising an image sensor configured to capture an image of the contaminant on the surface of the pellicle using an image sensor.

18. The system of clause 12, wherein the light source is further configured to illuminate the surface of the pellicle using a plurality of colors, and wherein, for each color of the plurality of colors, the
10 processor is further configured to determine the difference between the Raman spectra of the reference signal and the test signal and identify the presence of the contaminant.

19. A non-transitory computer readable medium storing one or more sequences of one or more instructions for execution by one or more processors to perform operations, comprising:
measuring a first value associated with a pellicle and/or a reticle surface;
15 illuminating the pellicle surface;
measuring a second value associated with the illuminated pellicle surface;
determining a difference between a Raman spectra of the first and second values; and
identifying a presence of a contaminant on the pellicle surface in response to the determining.

20. The non-transitory computer readable medium of clause 19, wherein the determining the first
20 value comprises:
using a detector comprising elements to measure a plurality of the first value at a plurality of locations of the pellicle and/or the reticle surface;
calculating a histogram for each of the elements;
performing a Gaussian fit on the histogram after removing any outliers from the histogram; and
25 deriving mean values from the Gaussian fit for the elements, wherein the mean values is used as the plurality of the first value.

[0080] The term “substrate” as used herein describes a material onto which material layers are added. In some embodiments, the substrate itself can be patterned and materials added on top of it may also be patterned, or may remain without patterning.

30 [0081] Although specific reference can be made in this text to the use of the apparatus and/or system according to the present disclosure in the manufacture of ICs, it should be explicitly understood that such an apparatus and/or system has many other possible applications. For example, it can be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, LCD panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the
35 context of such alternative applications, any use of the terms “reticle,” “wafer,” or “die” in this text should be considered as being replaced by the more general terms “mask,” “substrate,” and “target portion,” respectively.

[0082] While specific embodiments of the present disclosure have been described above, it will be appreciated that the present disclosure can be practiced otherwise than as described. The description is not intended to limit the present disclosure.

5 [0083] It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present disclosure as contemplated by the inventor(s), and thus, are not intended to limit the present disclosure and the appended claims in any way.

10 [0084] The present disclosure has been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

15 [0085] The foregoing description of the specific embodiments will so fully reveal the general nature of the present disclosure that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein.

20 [0086] The breadth and scope of protected subject matter should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

CLAIMS

1. A method, comprising:
measuring a first value associated with a pellicle and/or a reticle surface;
5 illuminating the pellicle surface;
measuring a second value associated with the illuminated pellicle surface;
determining a difference between a Raman spectra of the first and second values; and
identifying a presence of a contaminant on the pellicle surface in response to the determining.
- 10 2. The method of claim 1, further comprising:
identifying a contaminant type based on comparing the difference to a database of
known spectra of a plurality of contaminants, wherein the contaminant type comprises an
organic contaminant or an inorganic contaminant;
identifying a contamination source based on the contaminant type; and
15 identifying a remediation process for removing the contaminant based on the
contaminant type.
3. The method of claim 1, wherein the determining the first value comprises:
using a detector comprising elements to measure a scattered signal at a plurality of locations of
20 the pellicle and/or the reticle surface;
calculating a histogram for each of the elements;
performing a Gaussian fit on the histogram after removing any outliers from the histogram; and
deriving mean values from the Gaussian fit for the elements, wherein the mean values is used
as the first value, and wherein the mean values comprises a one dimensional array based on a number
25 of the elements.
4. The method of claim 1, further comprising moving a detector to a plurality of locations on the
pellicle during a scanning mode to scan the pellicle for contaminants at each of the plurality of locations.
- 30 5. The method of claim 1, further comprising capturing an image of the contaminant on the pellicle
surface.
6. The method of claim 1, wherein:
the illuminating the pellicle or the reticle surfaces comprises using a plurality of wavelengths,
35 and
the measuring the first value, the determining, and the identifying are performed for each of the
plurality of wavelengths.

7. A system, comprising:
a light source configured to illuminate a surface of a pellicle;
a scanner configured to scan the surface of the pellicle;
5 a spectrometer configured to measure a Raman spectrum of a test signal, the test signal being based on the illuminated surface of the pellicle; and
a processor configured to:
determine a difference between the Raman spectra of a reference signal and the test signal, the reference signal being based on a measurement from the surface of the pellicle and/or a reticle; and
10 identify a presence of a contaminant on the surface of the pellicle in response to detecting a deviation in the Raman spectra of the reference signal and the test signal.
8. The system of claim 7, wherein the processor is further configured to compare the deviation in the Raman spectra of the reference signal and the test signal to a database of known spectra of a plurality
15 of contaminants, and wherein the processor is further configured to identify a contaminant type based on the comparison.
9. The system of claim 8, wherein the processor is further configured to identify a contamination source based on the contaminant type.
20
10. The system of claim 8, wherein the processor is further configured to identify a remediation process for removing the contaminant based on the contaminant type
11. The system of claim 7, wherein the scanner is further configured to scan a plurality of locations
25 on the pellicle during the scanning mode to scan for contaminants at each of the plurality of locations.
12. The system of claim 7, further comprising an image sensor configured to capture an image of the contaminant on the surface of the pellicle using an image sensor.
- 30 13. The system of claim 7, wherein the light source is further configured to illuminate the surface of the pellicle using a plurality of colors, and wherein, for each color of the plurality of colors, the processor is further configured to determine the difference between the Raman spectra of the reference signal and the test signal and identify the presence of the contaminant.
14. A non-transitory computer readable medium storing one or more sequences of one or more
35 instructions for execution by one or more processors to perform operations, comprising:
measuring a first value associated with a pellicle and/or a reticle surface;
illuminating the pellicle surface;

measuring a second value associated with the illuminated pellicle surface;
determining a difference between a Raman spectra of the first and second values; and
identifying a presence of a contaminant on the pellicle surface in response to the determining.

- 5 15. The non-transitory computer readable medium of claim 14, wherein the determining the first value comprises:
- using a detector comprising elements to measure a plurality of the first value at a plurality of locations of the pellicle and/or the reticle surface;
- calculating a histogram for each of the elements;
- 10 performing a Gaussian fit on the histogram after removing any outliers from the histogram; and
- deriving mean values from the Gaussian fit for the elements, wherein the mean values is used as the plurality of the first value.

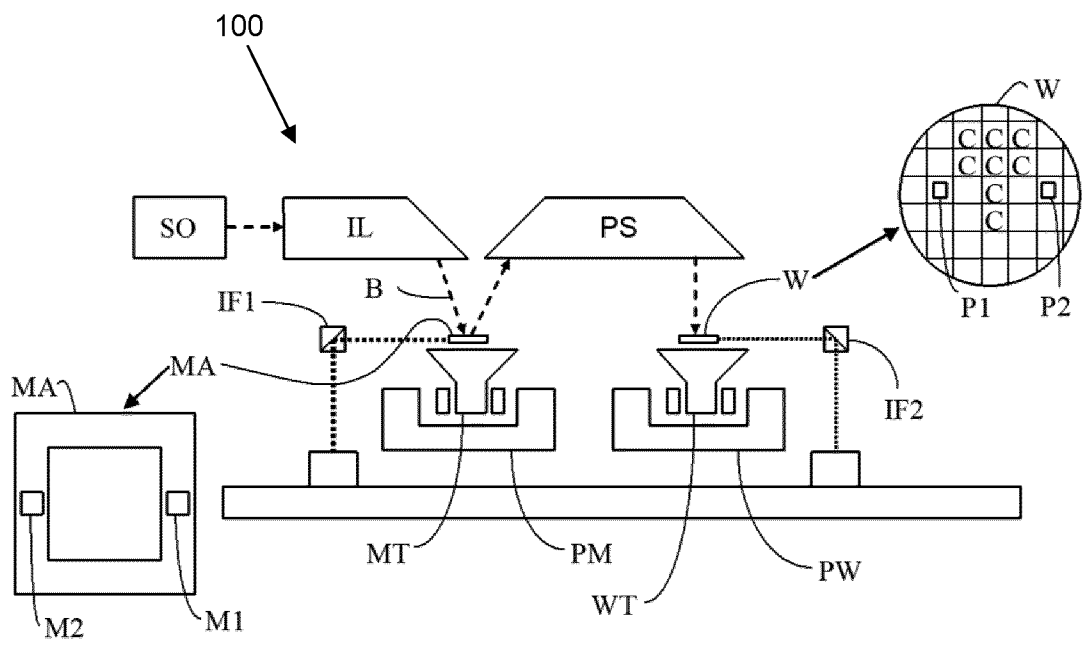


FIG. 1A

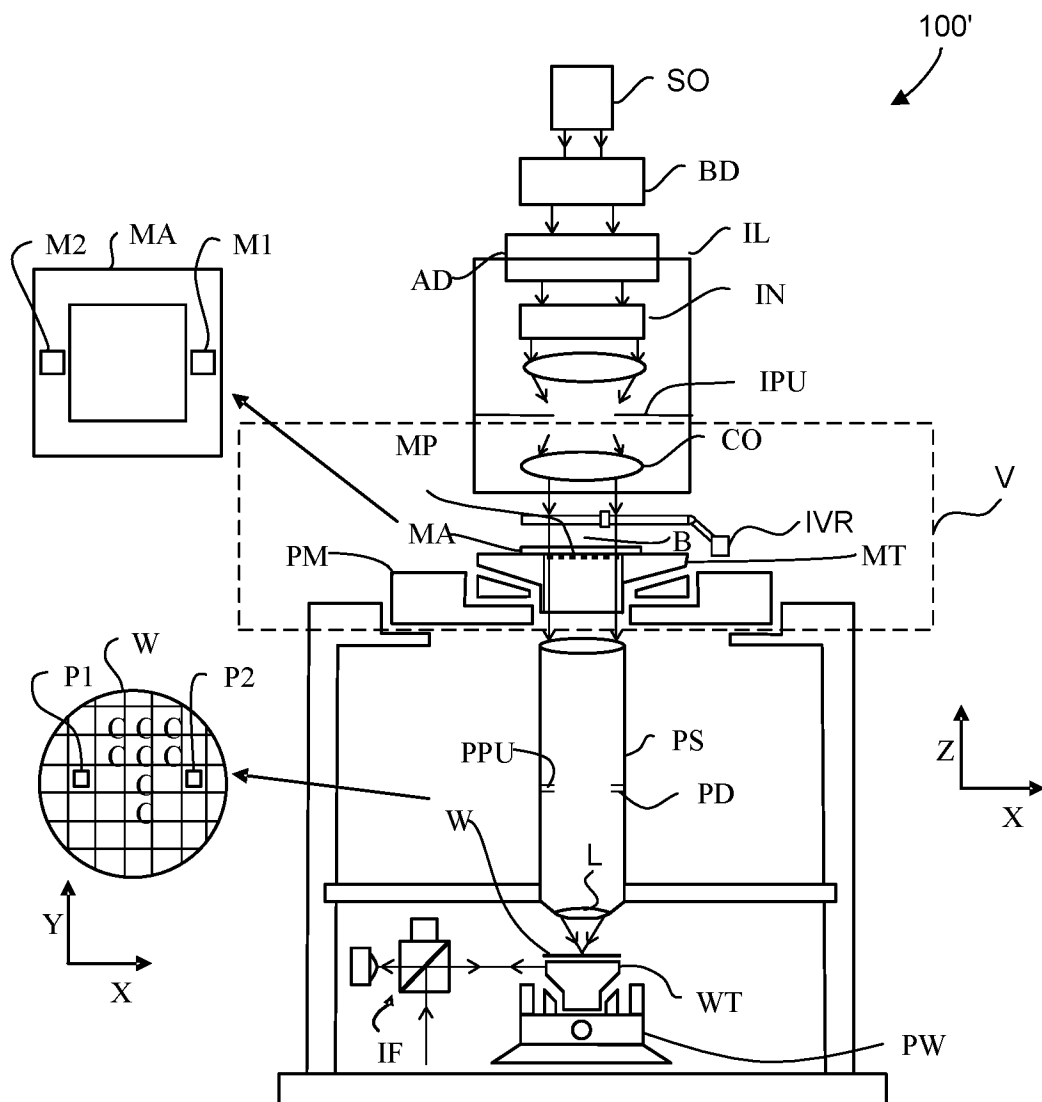


FIG. 1B

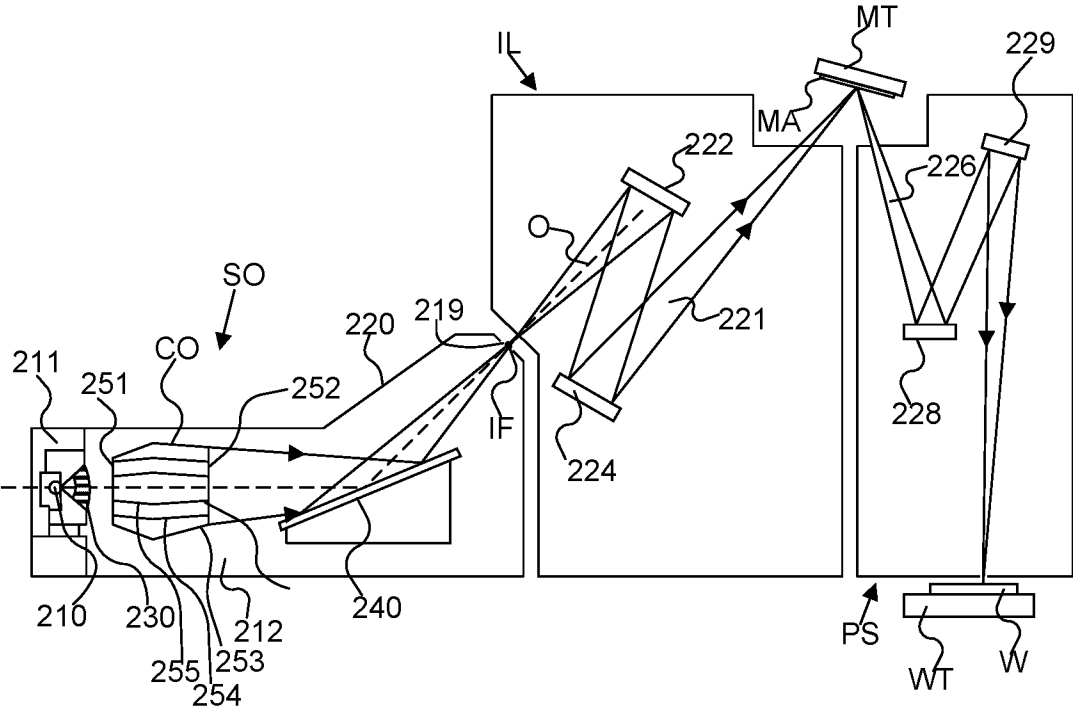


FIG. 2

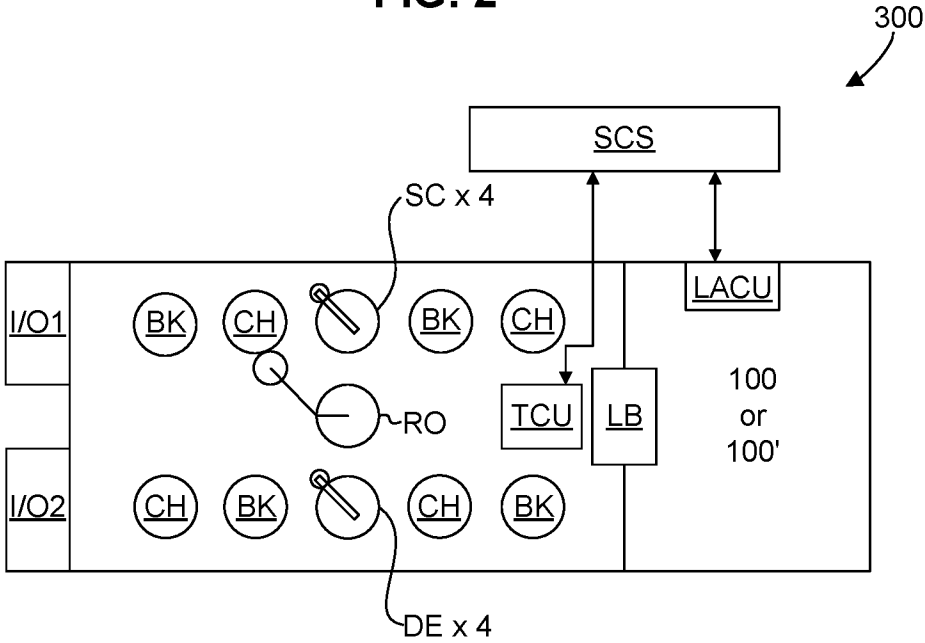


FIG. 3

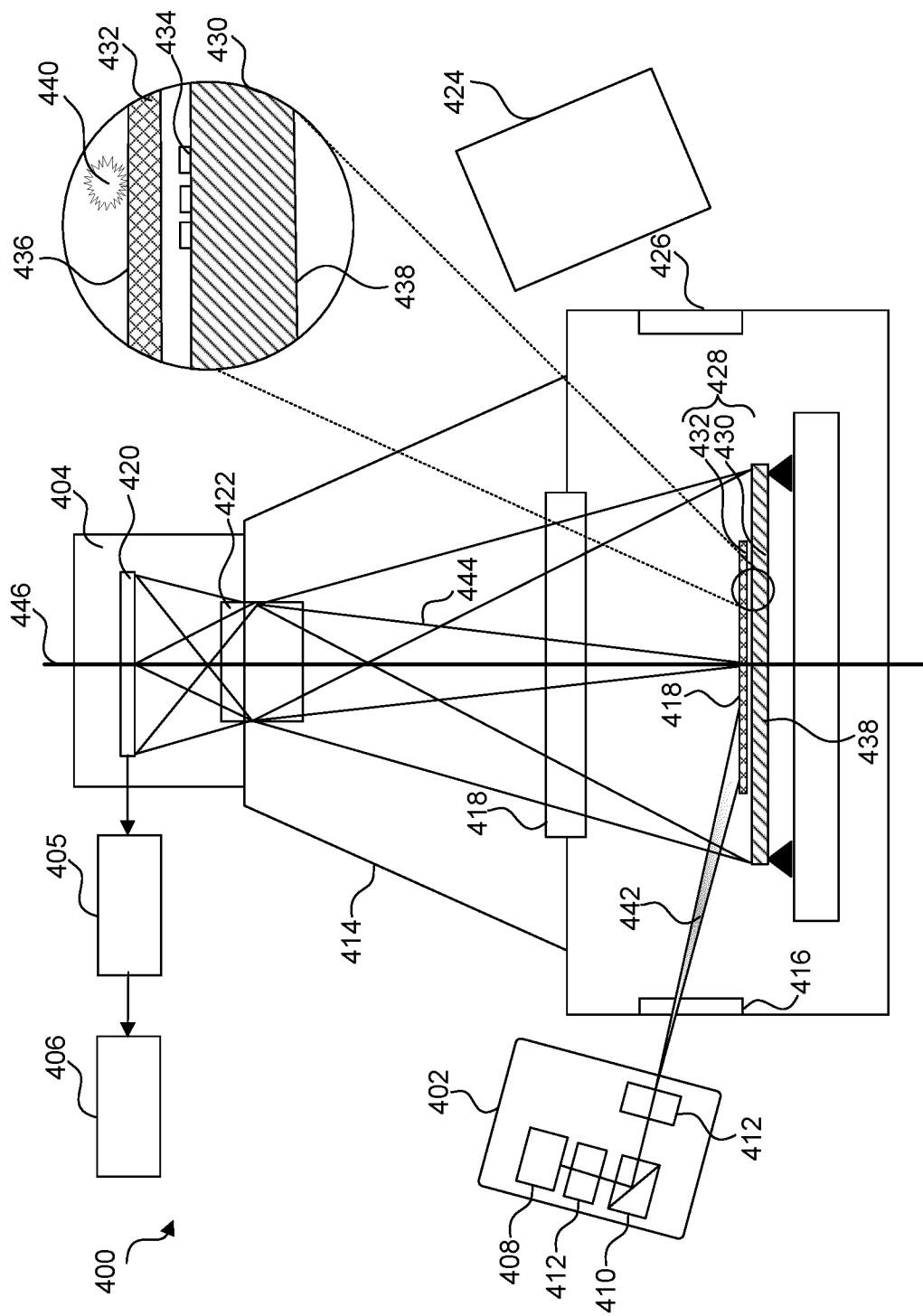


FIG. 4

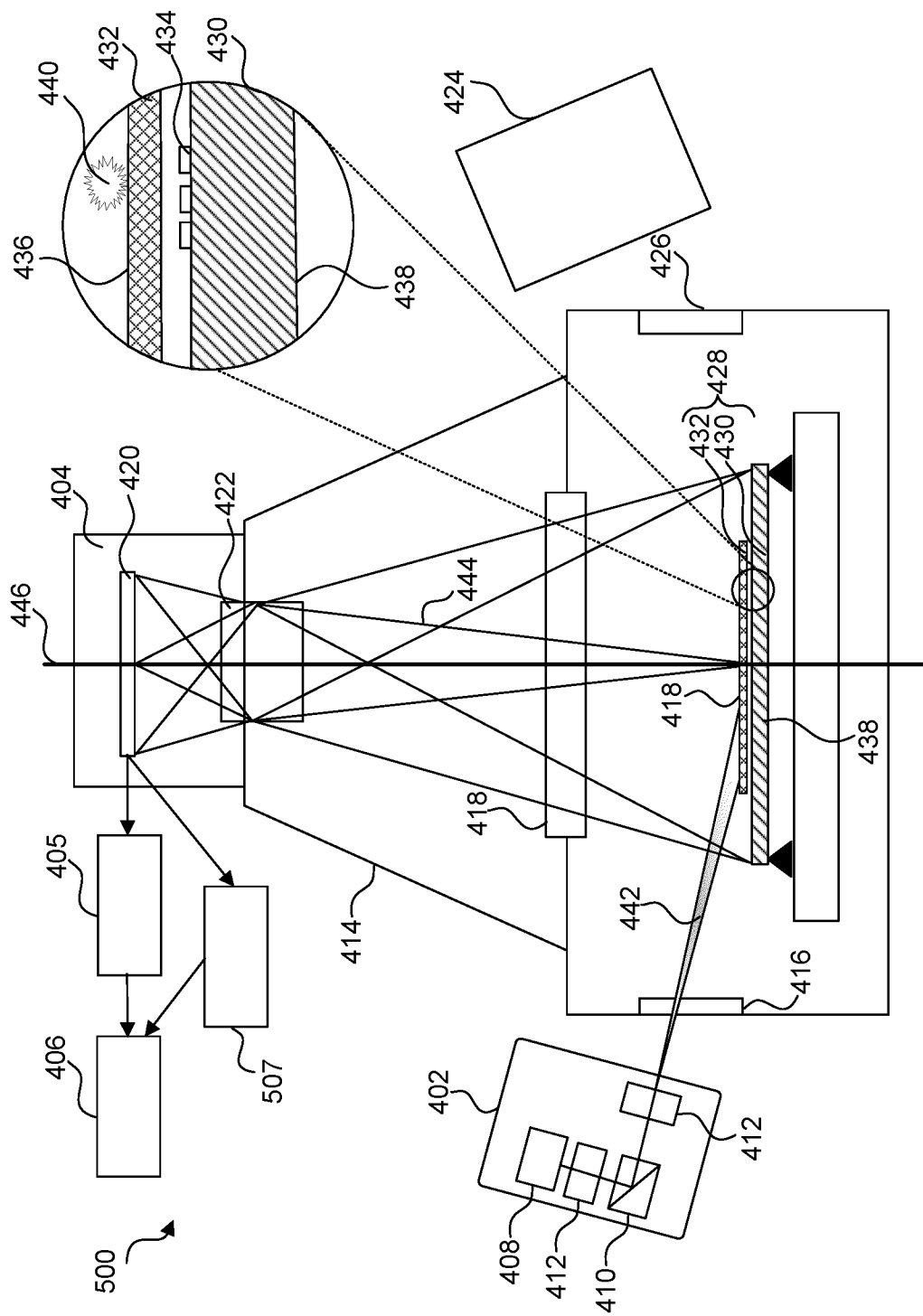


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/051403

A. CLASSIFICATION OF SUBJECT MATTER INV. G03F1/62 G01N21/65 G01N21/88 G03F1/84 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 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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020/341366 A1 (BROUNS DERK SERVATIUS GERTRUDA [BE] ET AL) 29 October 2020 (2020-10-29) abstract figures 1-3 paragraphs [0002], [0017], [0052], [0076], [0172] - [0174] -----	1-15
A	US 2013/313442 A1 (WANG LI [US] ET AL) 28 November 2013 (2013-11-28) abstract figure 3 paragraphs [0003], [0020] - [0024], [0030] - [0033] ----- -/--	1-15
☒ 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 27 April 2022		Date of mailing of the international search report 06/05/2022
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/EP2022/051403

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	AZIZIGHANNAD SAMAR ET AL: "Raman imaging of membrane fouling", SEPARATION AND PURIFICATION TECHNOLOGY, ELSEVIER SCIENCE, AMSTERDAM, NL, vol. 242, 28 February 2020 (2020-02-28), XP086137607, ISSN: 1383-5866, DOI: 10.1016/J.SEPPUR.2020.116763 [retrieved on 2020-02-28] the whole document -----	1-15
A	KÖGLER MARTIN ET AL: "Real-time Raman based approach for identification of biofouling", SENSORS AND ACTUATORS B: CHEMICAL, ELSEVIER BV, NL, vol. 230, 20 February 2016 (2016-02-20), pages 411-421, XP029506790, ISSN: 0925-4005, DOI: 10.1016/J.SNB.2016.02.079 the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2022/051403

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2020341366 A1	29-10-2020	CN 111480113 A	31-07-2020
		EP 3724721 A1	21-10-2020
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		NL 2022080 A	19-06-2019
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