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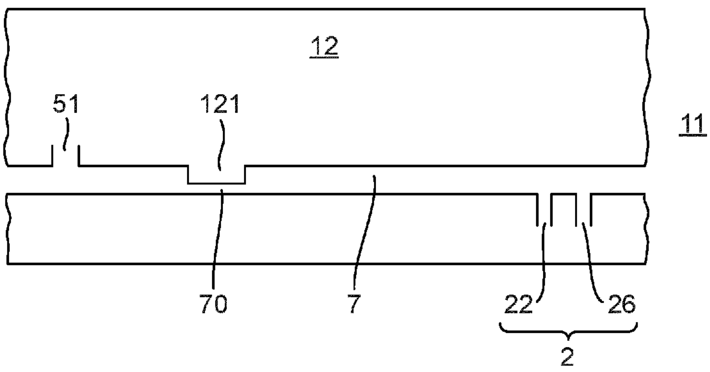
(54) **Title:** FLUID HANDLING STRUCTURE

Fig. 4



(57) **Abstract:** Disclosed herein is a fluid handling structure for an immersion lithographic apparatus. The fluid handling structure is configured to contain immersion fluid to a region. The fluid handling structure has, at a boundary of a space: at least one opening configured to supply the immersion fluid to the space; an extractor assembly configured to extract the immersion fluid from the space; a gas knife system radially outwards of the extractor assembly with respect to the space; and a chamber upstream of the gas knife system and in fluid communication with the gas knife system. The chamber comprises a flow equalisation structure such that gas flowing through the flow equalisation structure is uniform.

WO 2024/184006 A1

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FLUID HANDLING STRUCTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 23161009.8 which was filed on 9 March 2023 and of EP application 23184244.4 which was filed on 7 July 2023 and which are incorporated herein in their entirety by reference.

FIELD

[0002] The present invention relates to a fluid handling structure and a lithographic apparatus.

BACKGROUND

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

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

[0005] Further improvements in the resolution of smaller features may be achieved by providing an immersion fluid having a relatively high refractive index, such as water, on the substrate during exposure. The effect of the immersion fluid is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the fluid than in gas. The effect of the immersion fluid may also be regarded as increasing the effective numerical aperture (NA) of the system and also increasing the depth of focus.

[0006] The immersion fluid may be confined to a localized area, referred to as an immersion space, between a liquid confinement structure of the lithographic apparatus and the substrate by a fluid handling system. The fluid handling system may be an assembly comprising a number of component parts, some such parts having complicated and intricate structures. In particular, the fluid handling system provides an intricate system of flow channels for the fluid provided to the immersion space.

[0007] The performance of the fluid handling system can be sensitive to the uniformity of the flow of fluid. It may be desirable to influence the flow path of the fluid in order to achieve a desired pressure and flow of fluid downstream of the point of influence. An ability to influence flow may be dependent on dimensions of the structure defining the flow channel. Such dimensions may be limited by manufacturing constraints, such as issues of tolerances, time and cost to manufacture smaller structures.

SUMMARY

[0008] It is an object of the present invention to provide a fluid handling structure and lithographic apparatus comprising the fluid handling structure to improve fluid flow characteristics while maintaining acceptable manufacturing time and cost.

[0009] According to a first aspect of the invention, there is provided a fluid handling structure for an immersion lithographic apparatus. The fluid handling structure is configured to contain immersion fluid to a region. The fluid handling structure has, at a boundary of a space: at least one opening configured to supply the immersion fluid to the space; an extractor assembly configured to extract the immersion fluid from the space; a gas knife system radially outwards of the extractor assembly with respect to the space; and a chamber upstream of the gas knife system and in fluid communication with the gas knife system. The chamber comprises a flow equalisation structure such that gas flowing through the flow equalisation structure is uniform.

[0010] According to a second aspect of the invention, there is provided a lithographic apparatus comprising the fluid handling structure.

[0011] Further embodiments, features and advantages of the present invention, as well as the structure and operation of the various embodiments, features and advantages of the present invention, are described in detail below with reference to the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

[0012] 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:

[0013] Figure 1 depicts the schematic overview of the lithographic apparatus;

[0014] Figures 2a, 2b, 2c and 2d each depict, in cross section, two different versions of a fluid handling system with different features illustrated on the left hand side and the right hand side of each version, which may extend around the complete circumference;

[0015] Figure 3 depicts a plan view of a fluid handling structure;

[0016] Figure 4 depicts a side partial cross-sectional view of a fluid handling structure having a continuous slit;

[0017] Figure 5 depicts a side partial cross-sectional view of the flow space of a fluid handling structure having a plurality of discrete slits;

[0018] Figures 6a and 6b depict two different versions of the fluid handling structure of Figure 5, each having different patterns of the plurality of slits;

[0019] Figures 7a, 7b and 7c depict three different fluid handling structures, each providing a plurality of pillars having different configurations;

[0020] Figure 8a depicts a side partial cross-sectional view of the flow space of the fluid handling structure of Figure 7c, and Figure 8a depicts a partial plan view of the flow space and pillars of the fluid handling structure of Figure 7c;

[0021] Figure 9 depicts a side partial cross-sectional view of a fluid handling structure having a restrictive structure;

[0022] Figure 10 depicts a side partial cross-sectional view of a fluid handling structure having a continuous slit having a restrictive structure;

[0023] Figure 11a depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes an interior of which is filled with a porous material;

[0024] Figure 11b depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes defining gaps therebetween, wherein the gaps are filled with a porous material;

[0025] Figure 12a depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of rectangular cross-sectioned tubes an interior of which is filled with a porous material;

[0026] Figure 12b depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of rectangular cross-sectioned tubes defining gaps therebetween, wherein the gaps are filled with a porous material;

[0027] Figure 13a depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes arranged in a two-dimensional array, an interior of the tubes being filled with a porous material;

[0028] Figure 13b depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes arranged in a two-dimensional array, wherein the tubes define gaps therebetween, and the gaps are filled with a porous material;

[0029] Figure 14a depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes arranged in a close-packed two-dimensional array, an interior of the tubes being filled with a porous material;

[0030] Figure 14b depicts a view through cross-section A-A of an example restrictive structure of Figure 9, where the restrictive structure comprises a plurality of circular cross-sectioned tubes arranged in a close-packed two-dimensional array, wherein the tubes define gaps therebetween, and the gaps are filled with a porous material.

[0031] The features shown in the figures are not necessarily to scale, and the size and/or arrangement depicted is not limiting. It will be understood that the figures include optional features which may not be essential to the invention. Furthermore, not all of the features of the apparatus are depicted in each of the figures, and the figures may only show some of the components relevant for describing a particular feature.

DETAILED DESCRIPTION

[0032] In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm).

[0033] The term “reticle”, “mask” or “patterning device” as employed in this text may be broadly interpreted as referring to a generic patterning device that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate. The term “light valve” can also be used in this context. Besides the classic mask (transmissive or reflective, binary, phase-shifting, hybrid, etc.), examples of other such patterning devices include a programmable mirror array and a programmable LCD array.

[0034] Figure 1 schematically depicts a lithographic apparatus. The lithographic apparatus includes an illumination system (also referred to as illuminator) IL configured to condition a radiation beam B (e.g., UV radiation or DUV radiation), a mask support (e.g., a mask table) MT constructed to support a patterning device (e.g., a mask) MA and connected to a first positioner PM configured to accurately position the patterning device MA in accordance with certain parameters, a substrate support (e.g., a substrate table) 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 support WT in accordance with certain parameters, and a projection system (e.g., a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g., comprising one or more dies) of the substrate W. A controller 500 controls the overall operation of the apparatus. Controller 500 may be a centralised control system or a system of multiple separate sub-controllers within various sub-systems of the lithographic apparatus.

[0035] In operation, the illumination system IL receives the radiation beam B from a radiation source SO, e.g. via a beam delivery system BD. The illumination system IL may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic, and/or other types of optical components, or any combination thereof, for directing, shaping, and/or controlling radiation. The illuminator IL may be used to condition the radiation beam B to have a desired spatial and angular intensity distribution in its cross section at a plane of the patterning device MA.

[0036] The term “projection system” PS used herein should be broadly interpreted as encompassing various types of projection system, including refractive, reflective, catadioptric, anamorphic, magnetic, electromagnetic and/or electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, and/or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system” PS.

[0037] The lithographic apparatus is of a type wherein at least a portion of the substrate W may be covered by an immersion liquid having a relatively high refractive index, e.g., water, so as to fill a space 11 between the projection system PS and the substrate W – which is also referred to as immersion lithography. More information on immersion techniques is given in US 6,952,253, which is incorporated herein by reference.

[0038] The lithographic apparatus may be of a type having two or more substrate supports WT (also named “dual stage”). In such “multiple stage” machine, the substrate supports WT may be used in parallel, and/or steps in preparation of a subsequent exposure of the substrate W may be carried out on the substrate W located on one of the substrate support WT while another substrate W on the other substrate support WT is being used for exposing a pattern on the other substrate W.

[0039] In addition to the substrate support WT, the lithographic apparatus may comprise a measurement stage (not depicted in figures). The measurement stage is arranged to hold a sensor and/or a cleaning device. The sensor may be arranged to measure a property of the projection system PS or a property of the radiation beam B. The measurement stage may hold multiple sensors. The cleaning device may be arranged to clean part of the lithographic apparatus, for example a part of the projection system PS or a part of a system that provides the immersion liquid. The measurement stage may move beneath the projection system PS when the substrate support WT is away from the projection system PS.

[0040] In operation, the radiation beam B is incident on the patterning device, e.g. mask, MA which is held on the mask support MT, and is patterned by the pattern (design layout) present on patterning device MA. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and a position measurement system IF, the substrate support WT can be moved accurately, e.g., so as to position different target portions C in the path of the radiation beam B at a focused and aligned position. Similarly, the first positioner PM and possibly another position sensor (which is not explicitly depicted in Figure 1) may be used to accurately position the patterning device MA with respect to the path of the radiation beam B. Patterning device MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks P1, P2 as illustrated occupy dedicated target portions, they may be located in spaces between target portions. Substrate alignment marks P1, P2 are known as scribe-lane alignment marks when these are located between the target portions C.

[0041] To clarify the invention, a Cartesian coordinate system is used. The Cartesian coordinate system has three axis, i.e., an x-axis, a y-axis and a z-axis. Each of the three axis is orthogonal to the other two axis. A rotation around the x-axis is referred to as an Rx-rotation. A rotation around the y-axis is referred to as an Ry-rotation. A rotation around about the z-axis is referred to as an Rz-rotation. The x-axis and the y-axis define a horizontal plane, whereas the z-axis is in a vertical direction. The Cartesian coordinate system is not limiting the invention and is used for clarification only. Instead, another coordinate system, such as a cylindrical coordinate system, may be used to clarify the invention. The orientation of the Cartesian coordinate system may be different, for example, such that the z-axis has a component along the horizontal plane.

[0042] Immersion techniques have been introduced into lithographic systems to enable improved resolution of smaller features. In an immersion lithographic apparatus, a liquid layer of immersion liquid having a relatively high refractive index is interposed in the space 11 between a projection system PS of the apparatus (through which the patterned beam is projected towards the substrate W) and the substrate W. The immersion liquid covers at least the part of the substrate W under a final element of the projection system PS. Thus, at least the portion of the substrate W undergoing exposure is immersed in the immersion liquid.

[0043] In commercial immersion lithography, the immersion liquid is water. Typically the water is distilled water of high purity, such as Ultra-Pure Water (UPW) which is commonly used in semiconductor fabrication plants. In an immersion system, the UPW is often purified and it may undergo additional treatment steps before supply to the space 11 as immersion liquid. Other liquids with a high refractive index can be used besides water as the immersion liquid, for example: a hydrocarbon, such as a fluorohydrocarbon; and/or an aqueous solution. Further, other fluids besides liquid have been envisaged for use in immersion lithography.

[0044] In this specification, reference will be made in the description to localized immersion in which the immersion liquid is confined, in use, to the space 11 between the final element 100 and a surface facing the final element 100. The facing surface is a surface of substrate W or a surface of the supporting stage (or substrate support WT) that is co-planar with the surface of the substrate W. (Please note that reference in the following text to surface of the substrate W also refers in addition or in the alternative to the surface of the substrate support WT, unless expressly stated otherwise; and vice versa). A fluid handling structure 12 present between the projection system PS and the substrate support WT is used to confine the immersion liquid to the space 11. The space 11 filled by the immersion liquid is smaller in plan than the top surface of the substrate W and the space 11 remains substantially stationary relative to the projection system PS while the substrate W and substrate support WT move underneath.

[0045] Other immersion systems have been envisaged such as an unconfined immersion system (a so-called 'All Wet' immersion system) and a bath immersion system. In an unconfined immersion system, the immersion liquid covers more than the surface under the final element 100. The liquid outside the space 11 is present as a thin liquid film. The liquid may cover the whole surface of the substrate W or even the substrate W and the substrate support WT co-planar with the substrate W. In a bath type system, the substrate W is fully immersed in a bath of immersion liquid.

[0046] The fluid handling structure 12 is a structure which supplies the immersion liquid to the space 11, removes the immersion liquid from the space 11 and thereby confines the immersion liquid to the space 11. It includes features which are a part of a fluid supply system. The arrangement disclosed in PCT patent application publication no. WO 99/49504 is an early fluid handling structure comprising pipes which either supply or recover the immersion liquid from the space 11 and which operate depending on the relative motion of the stage beneath the projection system PS. In more recent designs, the fluid handling structure extends along at least a part of a boundary of the space 11 between the final element 100 of the projection system PS and the substrate support WT or substrate W, so as to in part define the space 11.

[0047] The fluid handing structure 12 may have a selection of different functions. Each function may be derived from a corresponding feature that enables the fluid handling structure 12 to achieve that function. The fluid handling structure 12 may be referred to by a number of different terms, each referring to a function, such as barrier member, seal member, fluid supply system, fluid removal system, liquid confinement structure, etc..

[0048] In an embodiment, immersion liquid is used as the immersion fluid. In that case the fluid handling structure 12 may be a liquid handling system. In reference to the aforementioned description, reference in this paragraph to a feature defined with respect to fluid may be understood to include a feature defined with respect to liquid.

[0049] A lithographic apparatus has a projection system PS. During exposure of a substrate W, the projection system PS projects a beam of patterned radiation onto the substrate W. To reach the substrate W, the path of the radiation beam B passes from the projection system PS through the immersion liquid confined by the fluid handling structure 12 between the projection system PS and the substrate W. The projection system PS has a lens element, the last in the path of the beam, which is in contact with the immersion liquid. This lens element which is in contact with the immersion liquid may be referred to as 'the last lens element' or "the final element". The final element 100 is at least partly surrounded by the fluid handling structure 12. The fluid handling structure 12 may confine the immersion liquid under the final element 100 and above the facing surface.

[0050] Figures 2a, 2b, 2c and 2d show different features which may be present in variations of a fluid handling system. The designs may share some of the same features as Figures 2a, 2b, 2c and 2d unless described differently. The features described herein may be selected individually or in combination as shown or as required. The figures depict different versions of a fluid handling system with different features illustrated on the left hand side and the right hand side, which may extend around the complete circumference. Thus, for example, the fluid handling system may have the same features extending around the complete circumference. For example, the fluid handling system may have only the features of the left hand side of Figure 2a, or the right hand side of Figure 2a, or the left hand side of Figure 2b, or the right hand side of Figure 2b, or the left hand side of 2c, or the right hand side of 2c, or the left hand side of 2d, or the right hand side of 2d. Alternatively, the fluid handling system may be provided with any combination of features from these figures at different locations around the circumference. The fluid handling system may comprise the fluid handling structure 12 as described in the variations below.

[0051] Figure 2a shows a fluid handling structure 12 around the bottom surface of the final element 100. The final element 100 has an inverted frusto-conical shape. The frusto-conical shape having a planar bottom surface and a conical surface. The frusto-conical shape protrudes from a planar surface and having a bottom planar surface. The bottom planar surface is the optically active portion of the bottom surface of the final element 100, through which the radiation beam B may pass. The final element 100 may have a coating 30. The fluid handling structure 12 surrounds at least part of the frusto-conical shape. The fluid handling structure 12 has an inner-surface which faces towards the conical surface of the frusto-conical shape. The inner-surface and the conical surface may have complementary shapes. A top surface of the fluid handling structure 12 may be substantially planar. The fluid handling structure 12 may fit around the frusto-conical shape of the final element 100. A bottom surface of the fluid handling structure 12 may be substantially planar and in use the bottom surface may be parallel with the facing surface of the substrate support WT and/or substrate W. Thus, the bottom surface of the fluid handling structure 12 may be referred to as a surface facing the surface of the substrate W. The distance between the bottom surface and the facing surface may be in the range of 20 to 500 micrometers, desirably in the range of 70 to 200 micrometers.

[0052] The fluid handling structure 12 extends closer to the facing surface of the substrate W and substrate support WT than the final element 100. The space 11 is therefore defined between the inner surface of the fluid handling structure 12, the planar surface of the frusto-conical portion and the facing surface. During use, the space 11 is filled with immersion liquid. The immersion liquid fills at least part of a buffer space between the complementary surfaces between the final element 100 and the fluid handling structure 12, in an embodiment at least part of the space between the complementary inner-surface and the conical surface.

[0053] The immersion liquid is supplied to the space 11 through an opening formed in a surface of the fluid handling structure 12. The immersion liquid may be supplied through a supply opening 20 in the inner-surface of the fluid handling structure 12. Alternatively or additionally, the immersion liquid is supplied from an under supply opening 23 formed in the bottom surface of the fluid handling structure 12. The under supply opening 23 may surround the path of the radiation beam B and it may be formed of a series of openings in an array or a single slit. The immersion liquid is supplied to fill the space 11 so that flow through the space 11 under the projection system PS is laminar. The supply of the immersion liquid from the under supply opening 23 additionally prevents the ingress of bubbles into the space 11. This supply of the immersion liquid may function as a liquid seal.

[0054] The immersion liquid may be recovered from a recovery opening 21 formed in the inner-surface. The recovery of the immersion liquid through the recovery opening 21 may be by application of an underpressure; the recovery through the recovery opening 21 as a consequence of the velocity of the immersion liquid flow through the space 11; or the recovery may be as a consequence of both. The recovery opening 21 may be located on the opposite side of the supply opening 20, when viewed in plan. Additionally or alternatively, the immersion liquid may be recovered through an overflow recovery 24 located on the top surface of the fluid handling structure 12. The supply opening 20 and recovery opening 21 can have their function swapped (i.e. the flow direction of liquid is reversed). This allows the direction of flow to be changed depending upon the relative motion of the fluid handling structure 12 and substrate W.

[0055] Additionally or alternatively, immersion liquid may be recovered from under the fluid handling structure 12 through a recovery opening 25 formed in its bottom surface. The recovery opening 25 may serve to hold a meniscus 33 of the immersion liquid to the fluid handling structure 12. The meniscus 33 forms between the fluid handling structure 12 and the facing surface and it serves as border between the liquid space and the gaseous external environment. The recovery opening 25 may be a porous plate which may recover the immersion liquid in a substantially single phase flow. The recovery opening in the bottom surface may be a series of pinning openings 32 through which the immersion liquid is recovered. The pinning openings 32 may recover the immersion liquid in a two phase flow.

[0056] Optionally radially outward, with respect to the inner-surface of the fluid handling structure 12, is a gas knife opening 26. Gas may be supplied through the gas knife opening 26 at elevated speed to assist liquid confinement of the immersion liquid in the space 11. The supplied gas may be humidified and it may contain substantially carbon dioxide. Radially outward of the gas knife opening 26 is a gas recovery opening 28 for recovering the gas supplied through the gas knife opening 26.

[0057] Further openings, for example open to atmosphere or to a gas source or to a vacuum, may be present in the bottom surface of the fluid handling structure 12, i.e. in the surface of the fluid handling structure 12 facing the substrate W. An example of such an optional further opening 50 is shown in dashed lines on the right hand side of Figure 2a. As shown, the further opening 50 may be a supply or extraction member, which is indicated by the double-headed arrow. For example, if configured as a supply, the further opening 50 may be connected to a liquid supply or a gas supply as with any of the supply members. Alternatively, if configured as an extraction, the further opening 50 may be used to extract fluid, and may for example, be connected to atmosphere or to a gas source or to a vacuum. For example, the at least one further opening 50 may be present between gas knife opening 26 and gas recovery opening 28, and/or between pinning openings 32 and gas knife opening 26.

[0058] The two different versions of the fluid handling structure 12 of the left and right sides of Figure 2a pin the meniscus 33. The version of the fluid handling structure 12 on the right hand side of Figure 2a may pin the meniscus 33 at a position that is substantially fixed with respect to the final element 100, due to the fixed position of the pinning opening 32. The version of the fluid handling structure 12 on the left hand side of Figure 2a may pin the meniscus 33 below the recovery opening 25, and thus the meniscus 33 may move along the length and/or width of the recovery opening 25. For the radiation beam B to be directed to a full side of the substrate W under exposure, the substrate support WT supporting the substrate W is moved relative to the projection system PS. To maximize the output of substrates W exposed by the lithographic apparatus, the substrate support WT (and so substrate W) is moved as fast as possible. However, there is a critical relative speed (often referred to as a critical scan speed) above which the meniscus 33 between the fluid handling structure 12 and the substrate W becomes unstable. An unstable meniscus 33 has a greater risk of losing immersion liquid, for example in the form of one or more droplets. Furthermore, an unstable meniscus 33 has a greater risk of resulting in the inclusion of gas bubbles in the immersion liquid, especially when the confined immersion liquid crosses the edge of the substrate W.

[0059] A droplet present on the surface of the substrate W may apply a thermal load and may be a source of defectivity. The droplet may evaporate leaving a drying stain, it may move transporting contamination such as a particle, it may collide with a larger body of immersion liquid introducing a bubble of gas into the larger body and it may evaporate, applying the thermal heat load to the surface on which it is located. Such a thermal load could be a cause of distortion and/or a source of a positioning error if the surface is associated with positioning of components of the lithographic apparatus relative to the substrate W being imaged. A formation of a droplet on a surface is therefore is undesirable. To avoid formation of such a droplet, the speed of the substrate support WT is thus limited to the critical scan speed at which the meniscus 33 remains stable. This limits the throughput of the lithographic apparatus.

[0060] The left hand side of the fluid handling system in Figure 2a may comprise a spring 60. The spring 60 may be an adjustable passive spring configured to apply a biasing force to the fluid handling structure 12 in the direction of the substrate W. Thus, the spring 60 can be used to control the height of the fluid handling structure 12 above the substrate W. Such adjustable passive springs are described in US 7,199,874 which is herein incorporated by reference in its entirety. Other bias devices may also be appropriate, for example, using an electromagnetic force. Although the spring 60 is shown with the left hand side of Figure 2a, it is optional and does not need to be included with the other features of the left hand side of Figure 2a. The spring 60 is not shown on any of the other figures, but could also be included with the other variations of the fluid handling system described in relation to Figures 2a, 2b, 2c, or 2d.

[0061] Figure 2b shows two different versions of the fluid handling structure 12 on its left side and on its right side, which allow movement of the meniscus 33 with respect to the final element 100. The meniscus 33 may move in the direction of the moving substrate W. This decreases the relative speed between the meniscus 33 and the moving substrate W, which may result in improved stability and a reduced risk of breakdown of the meniscus 33. The speed of the substrate W at which the meniscus 33 breaks down is increased so as to allow faster movement of the substrate W under the projection system PS. Throughput is thus increased.

[0062] Features shown in Figure 2b which are common to Figure 2a share the same reference numbers. The fluid handling structure 12 has an inner surface which complements the conical surface of the frusto-conical shape. The bottom surface of the fluid handling structure 12 is closer to the facing surface than the bottom planar surface of the frusto-conical shape.

[0063] Immersion liquid is supplied to the space 11 through supply openings 34 formed in the inner surface of the fluid handling structure 12. The supply openings 34 are located towards the bottom of the inner surface, perhaps below the bottom surface of the frusto-conical shape. The supply openings 34 are located around the inner surface, spaced apart around the path of the radiation beam B.

[0064] Immersion liquid is recovered from the space 11 through recovery openings 25, in the bottom surface of the fluid handling structure 12. As the facing surface moves under the fluid handling structure 12, the meniscus 33 may migrate over the surface of the recovery opening 25 in the same direction as the movement of the facing surface. The recovery openings 25 may be formed of a porous member. The immersion liquid may be recovered in single phase. The immersion liquid may be recovered in a two phase flow. The two phase flow is received in a chamber 35 within the fluid handling structure 12 where it is separated into liquid and gas. The liquid and gas are recovered through separate channels 36, 38 from the chamber 35.

[0065] An inner periphery 39 of the bottom surface of fluid handling structure 12 extends into the space 11 away from the inner surface to form a plate 40. The inner periphery 39 forms a small aperture which may be sized to match the shape and size of the radiation beam B. The plate 40 may serve to isolate the immersion liquid at either side of it. The supplied immersion liquid flows inwards towards the aperture, through the inner aperture and then under the plate 40 radially outwardly towards the surrounding the recovery openings 25.

[0066] The fluid handling structure 12 may be in two parts as shown on the right hand side of Figure 2b: an inner part 12a and an outer part 12b. The inner part 12a and the outer part 12b may move relatively to each other, mainly in a plane parallel to facing surface. The inner part 12a may have the supply openings 34 and it may have the overflow recovery 24. The outer part 12b may have the plate 40 and the recovery opening 25. The inner part 12a may have an intermediate recovery 42 for recovering the immersion liquid which flows between the inner part 12a and the outer part 12b.

[0067] The two different versions of the fluid handling structure of Figure 2b thus allow for movement of the meniscus 33 in the same direction as the substrate W, enabling faster scan speeds and increased throughput of the lithographic apparatus. However, the migration speed of meniscus 33 over the surface of the recovery opening 25 in the fluid handling structure 12 of the left side of Figure 2b may be slow. The fluid handling structure 12 of the right side of Figure 2b allows for quicker movement of the meniscus 33, by moving the outer part 12b with respect to the inner part 12a and the final element 100. However, it may be difficult to control the intermediate recovery 42 so as to ensure that enough immersion liquid is provided between the inner part 12a and the outer part 12b to prevent contact therebetween.

[0068] Figure 2c shows two different versions of the fluid handling structure 12 on its left side and on its right side, which may be used to pin the meniscus 33 of the immersion liquid to the fluid handling structure 12 as described above in relation to Figures 2a and/or 2b. Features shown in Figure 2c which are common to Figures 2a and/or 2b share the same reference numbers.

[0069] The fluid handling structure 12 has an inner surface which compliments the conical surface of the frusto-chronical shape. The bottom surface of the fluid handling structure 12 is closer to the facing surface than the bottom planar surface of the frusto-chronical shape. Immersion liquid is supplied to the space 11 delivered through an opening formed in a surface of the fluid handling structure 12. The immersion liquid may be supplied through a supply opening 34 in the inner surface of the fluid structure 12. Alternatively or additionally, the immersion liquid may be supplied through a supply opening 20 in the inner surface of the fluid structure 12. Alternatively or additionally, the immersion liquid is supplied through the under supply opening 23. The immersion liquid may be recovered via an extraction member, for example, via recovery opening 21 formed in the inner-surface and/or overflow recovery 24 and/or one or more openings in a surface of the fluid handling structure 12 as described below.

[0070] The two different versions of the fluid handling structure 12 of the left and right sides of Figure 2c pin the meniscus 33. The version of the fluid handling structure 12 on the right hand side of Figure 2c may pin the meniscus 33 at a position that is substantially fixed with respect to the final element 100, due to the fixed position of the recovery opening 32a. The version of the fluid handling structure 12 on the left hand side of Figure 2c may pin the meniscus 33 below the recovery opening 25, and thus the meniscus 33 may move along the length and/or width of the recovery opening 25.

[0071] As described above in relation to figure 2b, an inner periphery of the bottom surface of fluid handling structure 12 may extends into the space 11 away from the inner surface to form a plate 40 as shown on the left hand side. As described above, this may form a small aperture, and may isolate the immersion liquid at either side and/or cause immersion liquid to flow inwards towards the aperture, through the inner aperture and then under the plate 40 radially outwardly towards the surrounding the recovery openings 25. Although this features is shown on the left hand side in Figure 2c, it is optional in combination with the other features shown. Preferably, as shown on the left hand side, immersion liquid is supplied to the space 11 through supply openings 34 formed in the inner surface of the fluid handling structure 12. The supply openings 34 are located towards the bottom of the inner surface, perhaps below the bottom surface of the frusto-conical shape. The supply openings 34 are located around the inner surface, spaced apart around the path of the radiation beam B. Alternatively or additionally, the immersion liquid may be supplied through a supply opening 20 in the inner surface of the fluid structure 12. Alternatively or additionally, the immersion liquid is supplied through the under supply opening 23. Although the supply openings 34 are the preferred liquid supply, any combination of supply openings 34, supply openings 20 and/or under supply openings 23 may be provided.

[0072] As shown on the left hand side of Figure 2c, a fluid handling system may comprise the fluid handling structure 12 as described above and a further device 3000. The fluid handling structure 12 may have an extraction member, such as recovery opening 25, and a liquid supply opening, such as the under supply opening 23. It will be understood that the fluid handling structure 12 may comprise any configuration as disclosed in relation to the left hand of Figure 2a, the right hand side of Figure 2a, the left hand side of Figure 2b, the right hand side of Figure 2b or (as described below) the right hand side of Figure 2c, in combination with the further device 3000.

[0073] The further device 3000 may otherwise be referred to as a droplet catcher. The further device 3000 is provided to reduce occurrence of liquid on the surface of the substrate W after the fluid handling structure 12 has moved over the surface. The further device 3000 may comprise a liquid supply member 3010 and at least one extraction member 3020. The at least one extraction member 3020 may be formed in a shape surrounding the at least one supply member 3010 in plan. The at least one liquid supply member 3010 may be configured to provide a further liquid to a space 3110 between at least a part of the further device 3000 and the surface of the substrate W. The further device 3000 may be configured to recover at least some of the liquid via the at least one extraction member 3020. The further device 3000 may be used to incorporate any liquid left on the surface of the substrate W with the liquid in the space 3110 and then use the further device 3000 to extract the liquid such that the amount of liquid remaining on the surface of the substrate W is reduced.

[0074] The further device 3000 is shown as a separate device from the fluid handling structure 12 in Figure 2c. The further device 3000 may be positioned adjacent to the fluid handling structure 12. Alternatively, the further device 3000 may be part of, i.e. integral to, the fluid handling structure 12.

[0075] The further device 3000 may be configured to provide a liquid to the space 3110 which is separate from the liquid provided by the fluid handling structure 12.

[0076] Additionally or alternatively, the fluid handling structure 12 may have the components as shown on the right hand side of Figure 2c. More specifically, the fluid handling structure 12 may comprise the at least one liquid supply member, two extraction members (e.g., recovery openings 32a and 32b) and two gas supply members (e.g., gas supply openings 27a and 27b) formed on the surface of the fluid handling structure 12. Gas supply opening 27a can be omitted, i.e. is optional. The at least one liquid supply member may be the same as the under supply opening 23 in the bottom surface of the fluid handling structure 12 described above or the supply opening 20 or liquid supply openings 34 formed on the inner surface of the fluid handling structure 12 described in relation to left hand side of Figure 2b. The liquid supply member, the extraction members and the gas supply members may be formed on the surface of the fluid handling structure 12. Specifically, these components may be formed on a surface of the fluid handling structure 12 facing the substrate W, i.e. the bottom surface of the fluid handling structure 12.

[0077] At least one of the two extraction members may comprise a porous material 37 therein. The porous material 37 may be provided within an opening, e.g., recovery opening 32a through which fluid handling structure 12 extracts fluid from below the fluid handling structure 12 and may recover the immersion liquid in a single phase flow. The other of the two extraction members, e.g., recovery opening 32b may recover the immersion fluid as a dual phase extractor. The porous material 37 does not need to be flush with the bottom surface of the fluid handling structure 12.

[0078] Specifically, the fluid handling structure 12 may comprise the liquid supply member (e.g., under supply opening 23), with a first extraction member (e.g., recovery opening 32a) radially outwards of the liquid supply member, and a first gas supply member (e.g., gas supply opening 27a) radially outwards of the first extraction member, and the second extraction member (e.g., recovery opening 32b) radially outwards of the first gas supply member, and a second gas supply member (e.g., gas supply opening 27b) radially outwards of the second extraction member. Similar to Figure 2a, further openings, for example open to atmosphere or to a gas source or to a vacuum, may be present in the bottom surface of the fluid handling structure 12 as described previously (in relation to the fluid handling structure 12).

[0079] For example, at least one further opening (not shown) may be provided in the bottom surface of the fluid handling structure 12. The further opening is optional. The further opening may be arranged between the first extraction member (e.g., recovery opening 32a) and the first gas supply member (e.g., gas supply opening 27a) as described in the arrangement above. Alternatively or additionally, the further opening may be arranged between the second extraction member (e.g., recovery opening 32b) and the second gas supply member (e.g., gas supply opening 27b) as described in the arrangement above. The further opening may be the same as further opening 50 described above.

[0080] Optionally, the fluid handling structure 12 comprises a recess 29. The recess 29 may be provided between the recovery opening 32a and recovery opening 32b or gas supply opening 27a and recovery opening 32b. The shape of the recess 29 may be uniform around the fluid handling structure 12 and may optionally contain an inclined surface. In the case of the recess 29 provided between the recovery opening 32a and recovery opening 32b, the gas supply opening 27b may be provided on the inclined surface as shown in Figure 2c. In the case of the recess 29 provided between the supply opening 27a and recovery opening 32b, the gas supply opening 27b may be provided on the inclined surface or a part of the bottom surface of the fluid handling structure 12 which is parallel to the surface of the substrate W. Alternatively, the shape of the recess 29 may vary around the circumference of the fluid handling structure 12. The shape of the recess 29 may be varied to alter the impact of gas supplied from the gas supply members on the fluid below the fluid handling structure 12.

[0081] Figure 2d shows, in its left and right halves, two different versions of the fluid handling structure 12. The fluid handling structure 12 of the left half of Figure 2d has a liquid injection buffer 41a, which holds a buffer amount of immersion liquid, and liquid injection holes 41 which supply immersion liquid from the liquid injection buffer to the space 11. Outwardly of the liquid injection holes 41 are inner liquid recovery apertures 43 for conducting liquid to an inner recovery buffer 43a which is provided with a porous member. A recess 29 similar to that described relating to Figure 2c is provided outward of the inner liquid recovery apertures 43. Outward of the recess 29, in the lower face of the fluid handling structure 12 is a gas guiding groove 44 into which open outer recovery holes 44a. The outer recovery holes 44a lead a two-phase recovery flow to outer recovery buffer 44b which is also provided with a porous member. Outermost are gas sealing holes 45 which communicate between a gas sealing buffer volume 45a and the space underneath the fluid handling structure 12 to provide a gas flow to contain the immersion liquid.

[0082] The fluid handling structure 12 of the right half of Figure 2d has a liquid supply opening 20 in the inner inclined face thereof. In the underside of the fluid handling structure 12 there are (from inner side to outer side) an extraction opening 25 provided with a porous member 37; a first gas knife opening 26a, a second gas knife opening 26b and a third gas knife opening 26c. Each of these openings opens into a groove in the underside of the fluid handling structure 12 that provides a buffer volume. The outermost part of the fluid handling structure 12 is stepped so as to provide a greater separation between the fluid handling structure 12 and the substrate W.

[0083] Figures 2a-2d show examples of different configurations which can be used as part of a fluid handling system. It will be understood that the examples provided above refer to specific extraction members and recovery members, but it is not necessary to use the exact type of extraction member and/or recovery member. In some cases different terminology is used to indicate the position of the member, but the same functional features may be provided. Examples of the extraction member referred to above include recovery opening 21, overflow recover 24, recovery opening 25 (possibly comprising a porous plate and/or the chamber 35), gas recovery opening 28, pinning opening 32, recovery opening 32a, recovery opening 32b and/or the intermediate recovery 42. Examples of the supply member referred to above include supply opening 20, under supply opening 23, gas knife opening 26, gas supply opening 27a, gas supply opening 27b, and/or supply openings 34. In general, an extraction member used to extract/recover fluid, liquid or gas is interchangeable with at least any of the other examples used which extract/recover fluid, liquid or gas respectively. Similarly, a supply member used to supply fluid, liquid or gas is interchangeable with at least any of the other examples used which supply fluid, liquid or gas respectively. The extraction member may extract/recover fluid, liquid or gas from a space by being connected to an underpressure which draws the fluid, liquid or gas into the extraction member. The supply member may supply fluid, liquid or gas to the space by being connected to a relevant supply. Figure 3 shows a plan view of a fluid handling structure 12. The fluid handling structure 12 may be a fluid handling structure 12 for use in an immersion lithographic apparatus as described above. The fluid handling structure 12 has, at a boundary of the space 11 at least one opening configured to supply the immersion fluid to the space 11, an extractor assembly (not shown) configured to extract the immersion fluid from the space 11, and a gas knife system 2 radially outwards of the extractor assembly with respect to the space 11. The fluid handling structure 12 further comprises a chamber (not shown) upstream of the gas knife system 2 and in fluid communication with the gas knife system 2.

[0084] The fluid handling structure 12 is configured to contain immersion fluid to a region, or flow space, i.e., the space 11, such that the fluid can be provided to the gas knife system 2. As shown for example in Figure 3, the fluid handling structure 12 may comprise a fluid supply channel 80 having a fluid supply opening through which fluid can enter a chamber of the fluid handling structure 12. The fluid handling structure 12 surrounds the space 11 at a radial center of the fluid handling structure 12. The fluid handling structure 12 defines a flow space providing a flow path from the fluid supply channel 80 to a gas knife system 2.

[0085] It may be desirable to influence the flow path of the fluid in order to achieve a desired pressure and flow of fluid downstream of the point of influence. In particular, a fluid velocity and pressure may be greater in a region 81 of the chamber at or around the fluid supply channel 80 than a region 82 of the chamber farther from the fluid supply channel 80. The performance of the fluid handling system can be sensitive to the uniformity of the flow of fluid. In particular, it may be desirable to provide a uniform flow velocity through a fluid equalization structure. The pressure of the fluid may drop across the fluid equalization structure. Desirably the pressure drops is substantially uniform in a circumferential direction surrounding the space, and in particular surrounding the gas knife system 2.

[0086] As shown in Figure 3, the chamber of the fluid handling structure 12 comprises a flow equalization structure 70. The flow equalization structure 70 is configured such that fluid, such as gas, flowing through the flow equalization structure 70 is uniform. In particular, it may be desirable to configure the fluid handling structure 12 such that fluid flow, for example flow velocity and pressure, is more uniform and/or is at a lower pressure in a region 83 radially inward of the flow equalization structure 70 than in a region 81, 82 radially outward of the flow equalization structure 70 with respect to the space 11.

[0087] In other words, the flow equalization structure 70 may be configured such that a pressure drop of fluid from a position directly radially outward of the flow equalization structure 70 and a position directly radially inward of the flow equalization structure 70, with respect to the space 11, is between 10 mbar and 200 mbar, desirably between 15 mbar and 150 mbar, more desirably between 20 mbar and 120 mbar, yet more desirably between 40 mbar and 100 mbar. In particular, the pressure drop of fluid across the flow equalization structure 70 is desirably generally uniform in a circumferential direction with respect to the space 11. In other words, for at least 270 degrees, and preferably 300 degrees, in a circumferential direction, it is desirable that the pressure drop remains within a range of plus or minus 20 mbar, preferably 10 mbar, more preferably 5 mbar.

[0088] Furthermore, it is desirable that the flow equalization structure 70 is configured such that a volumetric flow rate between the flow equalization structure 70 and the gas knife system 2 is desirably generally uniform in a circumferential direction with respect to the space 11. In other words, for at least 270 degrees, and preferably 300 degrees, in a circumferential direction, it is desirable that the pressure drop remains within a range of plus or minus 60 NLPM, desirably 50 NLPM, more desirably 40 NLPM, yet more desirably 30 NLPM, and yet more desirably 25 NLPM.

[0089] The gas knife system 2 comprises at least one gas knife opening 26 radially outwards of the extractor assembly with respect to the space 11. The gas knife system 2 comprises at least one gas supply opening 22 radially outwards of the at least one gas knife opening 26 relative to the space 11. The fluid handling structure 12 desirably comprises a flow restriction upstream of the at least one gas supply opening 22. The flow restriction is desirably configured such that fluid, particularly gas, exiting the at least one gas knife opening 26 is at a higher fluid velocity than fluid exiting the at least one gas supply opening 22. The flow equalization structure 70 may comprise the flow restriction. In other words, the flow equalization structure 70 is desirably upstream of the at least one gas supply opening 22 and the flow equalization structure 70 is desirably configured such that fluid, particularly gas, exiting the at least one gas knife opening 26 is at a higher fluid velocity than fluid exiting the at least one gas supply opening 22.

[0090] An ability to influence flow may be dependent on dimensions of the structure defining the flow channel. Such dimensions may be limited by manufacturing constraints, such as issues of tolerances, time and cost to manufacture smaller structures.

[0091] Figure 4 depicts a cross-section through the flow path showing a side view of an example arrangement of a fluid handling structure 12, having at least one opening 51 through which gas is provided along a flow path through to a chamber 7 and on to a gas knife opening 26. As shown in the arrangement of Figure 4, a flow equalization structure 70 is provided radially outward of the gas knife opening 26, with respect to the space 11. In particular, in this example, the flow equalization structure 70 is provided radially inward of the at least one opening 51 and radially outward of the gas knife opening 26, with respect to the space 11.

[0092] There may be additional components, not shown in Figure 4. For example, the extractor assembly is not shown in Figure 4. In particular, there may be one or more additional components provided between the fluid handling structure 12 and the space 11. Alternatively, or additionally, the fluid handling structure 12 may comprise more components than depicted in Figure 4. In particular, the fluid handling structure 12 may comprise one or more components between the gas knife opening 26 and the space 11.

[0093] In the exemplary arrangement of Figure 4, the flow equalization structure 70 is provided in the chamber 7, closer to the at least one opening 51 than the gas knife opening 26 in a radial direction with respect to the space 11. In an alternative arrangement, the flow equalization structure 70 may be provided closer to the gas knife opening 26 than the at least one opening 51 in a radial direction with respect to the space 11.

[0094] The flow equalization structure 70 is desirably configured to obstruct a flow path of fluid flowing from the at least one opening 51 to the gas knife system 2. As shown, for example, in Figure 4, the flow equalization structure 70 may form a slit in the chamber 7. The slit is a region of the flow path having a height less than a height of the chamber 7 adjacent to the slit. In other words, the fluid handling structure 12 may comprise a protruding section 121 which protrudes from a ceiling of the chamber 7 to form a region of the chamber 7 in which the flow path has a smaller cross-sectional area. In this way, the flow of fluid may be restricted in the slit, below the protruding section 121, compared to other regions of the flow path. In an alternative arrangement, the fluid handling structure 12 may comprise a protruding section which protrudes from a floor of the chamber 7 to form a region of the chamber 7 in which the flow path has a smaller cross-sectional area.

[0095] In the arrangement of Figure 4, the height of the at least one slit is less than a height of the chamber 7 directly upstream of the at least one slit and less than a height of the chamber 7 directly downstream of the at least one slit. Similarly, in the arrangement of Figure 4, the height of the at least one slit is also less than a height of the chamber 7 directly radially outward of the at least one slit and less than a height of the chamber 7 directly radially inwards of the at least one slit. In the arrangement of Figure 4, the height of the at least one slit may be increased by reducing a thickness of the protruding section 121 or the height of the at least one slit may be reduced by increasing a thickness of the protruding section 121. The height of the slit is desirably between 200 microns and 600 microns, more desirably between 300 microns and 500 microns, yet more desirably between 300 microns and 400 microns.

[0096] The length of the at least one slit (in a radial direction) is desirably between 0.1 mm and 10 mm, more desirably between 0.5 mm and 5 mm, yet more desirably between 0.75 mm and 1.25 mm, and yet more desirably 1 mm. Increasing length of the slit, in a radial direction, may increase the drop in pressure of fluid across the slit (from radially outward of the slit to radially inward of the slit).

[0097] There the flow equalization structure 70 may form a single continuous slit, for example as shown in Figure 3. In the arrangement of Figure 3, the single continuous slit completely surround the gas knife system 2. In other words, the slit is continuous in a circumferential direction around the gas knife system 2. The slit of Figure 3 is a single continuous slit forming a continuous circular shape. Alternatively, the slit may take a continuous non-circular shape, such as a substantially diamond shape, square shape, an octagonal shape or a star shape, for example.

[0098] Alternatively to being a single continuous slit, the flow equalization structure 71 may comprise a plurality of discrete slits, for example as shown in Figure 5. Figure 5 depicts a cross-sectional view through the flow path of an exemplary arrangement of a fluid handling structure 12. Figure 5 shows the flow space, with fluid handling structure 12 surrounding and defining the flow space not shown. In the arrangement of Figure 5, the flow equalization structure 71 comprises a plurality of slits 710. In other words, the fluid handling structure 12 defines a plurality of slits 710. The fluid handling structure 12 may comprise a plurality of pillars 711. Each of the plurality of pillars 711 may be disposed in a position between two adjacent slits 710. Each pillar 711 may extend the entire height of the chamber 7. In other words, each pillar 711 may extend from the floor to the ceiling of the chamber 7. In this way, the pillars 711 may be configured to prevent flow of fluid between the slits 710. As such, fluid may be directed along the flow path through the plurality of slits 710 and radially inward towards the gas knife system 2.

[0099] The plurality of slits 710 may consist of between 50 and 300 slits, desirably between 75 and 200 slits, more desirably between 80 and 150 slits, yet more desirably 100 slits. The plurality of slits 710 are desirably arranged to surround the gas knife system 2 and configured to direct fluid on a flow path toward the gas knife system 2. The plurality of slits 710 are preferably distributed evenly in a circumferential direction around the gas knife system 2, with respect to the space 11.

[0100] It is desirable that each slit of the plurality of slits 710 extends to direct a flow path of fluid in a radial direction with respect to the space 11. In other words, a longitudinal direction of each slit 710 is desirably a radial direction. Each of the plurality of slits 710 may be configured to direct the fluid from a position radially outward of the respective slit to 710 a position radially inward of the respective slit 710.

[0101] The height of each slit of the plurality of slits 710 is desirably between 200 microns and 600 microns, more desirably between 300 microns and 500 microns, yet more desirably between 300 microns and 400 microns. The width of each of the plurality of slits 710, in a circumferential direction (or a direction tangential to the radial direction) is desirably greater than or equal to the height of the corresponding slit 710. Each slit 710 desirably has a width equal to the distance between adjacent slits 710. In other words, the width of the pillar 711 between adjacent slits 710 may be equal to the width of each slit 710. Alternatively, the width of each pillar 711 may be greater than or smaller than the width of the slit 710 defined between adjacent pillars 711. The height of each of the pillars 711 is preferably equal to or greater than the height of the slit 710 adjacent to the pillar 711.

[0102] The plurality of discrete slits 710 may be beneficial in comparison to a single continuous slit because the desired uniformity of flow may be achieved with a plurality of slits 710 having a greater height than the height of a single continuous slit required to achieve similar levels of uniformity of flow. In other words, the use of a plurality of discrete slits 710 may allow the desired flow characteristics to be achieved with the slits 710 having a greater height than would be required with a single continuous slit. The greater height may have the advantage of being more readily achieved through use of additive manufacturing to manufacture the fluid handling structure 12 surrounding and defining the slits 710. Furthermore, the greater height of the slits 710 may have the advantage that the desired flow characteristics can be achieved more reliably due to being less sensitive to the tolerance of the height of the slit 710. In other words, the plurality of slits 710 may achieve the desired flow characteristics within a greater range of height tolerance than a single continuous slit.

[0103] Each slit of the plurality of slits 710 of the flow equalization structure 71 is disposed at a discrete location such that the plurality of slits 710 forms a pattern of slits 710 surrounding the gas knife system 2. The pattern of slits 710 may, for example, form a circular pattern, a diamond pattern, a square pattern or a star-shaped pattern. Figure 6a and 6b depict plan views of arrangements of the fluid handling structure 12 having different patterns of the plurality of slits 710. In other words, the Figure 6a and 6b depict plan views of arrangements of the fluid handling structure 12 having different arrangements of pillars 711 which separate a plurality of slits 710 or channels through which fluid can pass along a flow path to the gas knife system 2.

[0104] In the exemplary arrangement of Figure 6a, the pattern of slits 710 form a non-circular pattern, in particular a substantially square pattern. Alternatively, the non-circular pattern could be any substantially polygon pattern. In the exemplary arrangement of Figure 6b, the pattern of slits 710 form a substantially circular pattern. Optionally, each slit of the plurality of slits 710 may be equidistant from a radial perimeter 17 of the chamber in a radial direction with respect to the space 11. The majority of slits of the plurality of slits 710 may be closer to a radial perimeter 17 of the chamber than to the gas knife system 2, as shown for example in the arrangement of Figure 6b. Optionally, each slit of the plurality of slits 710 may be equidistant from the gas knife system 2 in a radial direction with respect to the space 11, as shown for example in Figure 6b.

[0105] Instead of, or in addition to, comprising one or more protruding sections to form one or more slits, the flow equalization structure 72, 73, 74 may comprise a plurality of pillars. The pillars may otherwise be referred to as plates or vanes. The pillars are configured to prevent fluid from flowing at the position of the pillars. In other words, the pillars define the flow path of fluid as the pillars are configured such that fluid flows around the pillars. Each pillar of the plurality of pillars is disposed at a discrete location such that the plurality of pillars forms a pattern of pillars surrounding the gas knife system 2. The pattern of pillars may, for example, form a circular pattern, a diamond pattern, a square pattern or a star-shaped pattern.

[0106] The height of each pillar is preferably equal to a height of the chamber. In other words, each pillar may extend from the floor of the chamber to the ceiling of the chamber. The plurality of pillars therefore define a plurality of flow channels, wherein each flow channel is provided between adjacent pillars. The flow channels being regions of the chamber where fluid is able to flow, for example from an opening to the gas knife system 2 which is radially inward of the opening with respect to the space 11.

[0107] As shown, for example, in the arrangements of Figures 7a-7c, the flow equalization structure 72, 73, 74 may comprise a plurality rows of pillars 721-723, 731-733, 741-743. The plurality of rows of pillars 721-723, 731-733, 741-743 are desirably configured to direct a flow path of fluid in a radial direction with respect to the space 11. In particular, the plurality of rows of pillars 721-723, 731-733, 741-743 may be configured to define channels between the pillars 721-723, 731-733, 741-743, wherein the channels provide a flow path for fluid flowing from a region radially outward of the plurality of rows of pillars 721-723, 731-733, 741-743, to a region radially inward of the plurality of rows of pillars 721-723, 731-733, 741-743, with respect to the space 11.

[0108] As shown, for example, in the arrangements of Figures 7a-7c, the plurality rows of pillars 721-723, 731-733, 741-743 are desirably arranged concentrically. The plurality rows of pillars 721-723, 731-733, 741-743 comprises an outer row of pillars 721, 731, 741 and an inner row of pillars 723, 733, 743 radially inwards of the outer row of pillars 721, 731, 741 with respect to the space 11. In the arrangements of Figures 7a-7c, the plurality rows of pillars comprises a middle row of pillars 722, 732, 742 radially inwards of the outer row of pillars 721, 731, 741, and radially outwards of the inner row of pillars 723, 733, 743. With these arrangements, the flow path of the fluid may extend from a radially outward position, between adjacent pillars of an outward row of pillars 721, 731, 741, and then between adjacent pillars of a middle row of pillars 722, 732, 742, and then between adjacent pillars of an inward row of pillars 723, 733, 743. Alternatively to the plurality of rows of pillars consisting of three rows of pillars, there may be only two rows of pillars, or there may be more than three rows of pillars.

[0109] As shown, for example, in the arrangements of Figures 7a-7c, two or more of the plurality rows of pillars 721-723, 731-733, 741-743 may be arranged in a staggered manner. In particular, the pillars 721-723, 731-733, 741-743 of adjacent rows may be offset from each other in a circumferential direction with respect to the space 11. There may be additional components, not shown in Figure 7a-7c, provided between the fluid handling structure 12 and the space 11. Alternatively, or additionally, the fluid handling structure 12 may comprise more components than depicted in Figure 7a-7c. In particular, the fluid handling structure 12 may comprise components between the gas knife system 2 and the space 11.

[0110] In the arrangements of Figure 7a and 7b, the middle row of pillars 732, 742 is offset in a circumferential direction from the outer row of pillars 731, 741. Furthermore, in the arrangements of Figure 7a and 7b, the inner row of pillars 733, 743 is offset in a circumferential direction from the middle row of pillars 732, 742. The adjacent rows of pillars 731-733, 741-743 are desirably offset from each other in a circumferential direction such that a flow path of fluid from a position radially outward of the rows of pillars 731-733, 741-743 to a position radially inward of the rows of pillars 731-733, 741-743 is indirect. The rows of pillars 731-733, 741-743 are desirably configured such that there is not a direct path in a radial direction between the rows of pillars 731-733, 741-743. In other words, it is desirable that adjacent rows of pillars 731-733, 741-743 define a flow path in non-radial direction, and more desirably a flow path in a circumferential direction, with respect to the space 11.

[0111] As shown for example in the arrangement of Figure 7a, the pillars of the inner row of pillars 733 may be shorter in a longitudinal direction than pillars of the outer row of pillars 731. In other words, the pillars of the inner row of pillars 733 may be shorter in a circumferential direction, with respect to the space 11, than pillars of the outer row of pillars 731. In this arrangement, the number of pillars in the inner row of pillars 733 is greater than the number of pillars in the outer row of pillars 731.

[0112] As shown in Figure 7a, there may optionally further be a middle row of pillars 732. In such an arrangement, the pillars of the middle row of pillars 732 are desirably shorter (in a longitudinal direction approximately aligned in the circumferential direction) than pillars of the outer row of pillars 731. Furthermore, pillars of the middle row of pillars 732 are desirably longer (in a longitudinal direction approximately aligned in the circumferential direction) than pillars of the inner row of pillars 731. The number of pillars in the middle row of pillars 732 in the arrangement of Figure 7a is greater than the number of pillars in the outer row of pillars 731, and the number of pillars in the middle row of pillars 732 is fewer than the number of pillars in the inner row of pillars 733.

[0113] In a preferred arrangement, the number of pillars may increase exponentially from the outer row of pillars 731, to the middle row of pillars 732 and to the inner row of pillars 733. The number of pillars in the middle row of pillars 732 may be double the number of pillars in the outer row of pillars 731. The number of pillars in the inner row of pillars 733 may be double the number of pillars in the middle row of pillars 732.

[0114] With the greater number of pillars in the inner row of pillars 733, there are a greater number of channels between adjacent pillars in the inner row of pillars 733. The greater number of channels through which fluid may flow means that each channel has less fluid flowing though it than if the number of channels were lower. Thus the fluid flow may be more evenly distributed around the circumference surrounding the gas knife system 2, instead of having a smaller number of discrete flow channels of flow. As such, an improved uniformity of flow may be achieved by providing an arrangement with a greater number of pillars in the row of pillars radially closest to the gas knife system 2 compared to the one or more rows further from the gas knife system 2 in a radial direction relative to the space 11.

[0115] As shown in the arrangement of Figure 7a, the pillars 731-733 may have a non-circular cross-section. In particular, the pillars of the inner row of pillars 733 may have a non-circular cross-section. The inner row of pillars 733 are desirably aligned with the radial direction towards the center of the space 11. In other words, the inner row of pillars 733 may extend in a radial direction and may have a length in the radial direction greater than a length in a circumferential direction (or a direction tangential to the radial direction). The inner row of pillars 733 may be aligned such that fluid flowing through openings, or channels, defined between adjacent pillars of the inner row of pillars 733 are aligned with the radial direction. In other words, the inner row of pillars 733 may be configured to direct a flow path in a radial direction, such that fluid flowing from directly radially outwards of the inner row of pillars 733 to radially inwards of the inner row of pillars 733 is directed to flow in a radial direction towards the center of the space 11. In this way the flow may be aligned in a preferred direction as it is directed towards the gas knife system 2.

[0116] As shown for example in the arrangement of Figure 7b, each of the plurality of pillars 741-743 may have a circular cross-section. In the arrangement of Figure 7b, the pillars of the middle row of pillars 742 are offset in a circumferential direction from the pillars of the outer row of pillars 741. The pillars of the inner row of pillars 743 are offset in a circumferential direction from the pillars of the middle row of pillars 742. The pillars of the inner row of pillars 743 may be aligned in a circumferential direction to the pillars of the outer row of pillars 741.

[0117] The number of pillars 741-743 in each row may be equal. Alternatively, the number of pillars 741-743 in each row may increase with decreasing distance to the center of the space 11 in a radial direction of the space 11. In other words, the number of pillars in the middle row of pillars 742 may be greater than the number of pillars in the outer row of pillars 741, and/or the number of pillars in the inner row of pillars 743 may be greater than the number of pillars in the middle row of pillars 742. For example, the number of pillars 741-743 may increase exponentially from the outer row of pillars 741, to the middle row of pillars 742 and to the inner row of pillars 743.

[0118] The plurality of pillars 741-743 may form a tessellated pattern of pillars, as shown for example in Figure 7b. In the arrangement of Figure 7b, each of the pillars 741-743 has a circular cross-section. In another arrangement, each of the plurality of pillars 741-743 may have a non-circular cross-section. For example, each of the pillars 741-743 may have a square, hexagonal, or octagonal cross-section.

[0119] In an alternative arrangement, the pillars of one or more rows of the plurality of rows of pillars 741-743 may have a circular cross-section and the pillars of one or more other rows of the plurality of rows of pillars 741-743 may have a non-circular cross-section.

[0120] As shown in the arrangements of Figure 7a and 7c, each pillar 721-723, 731-733 may have a non-circular cross-section. The non-circular shape of the cross-section is desirably a rectangular shape. Alternatively, the pillars 721-723, 731-733 may, for example, have a trapezoidal, an elliptical or aerofoil shaped cross-section.

[0121] In an alternative arrangement, the pillars of one or more rows of the plurality of rows of pillars 721-723, 731-733 may have a non-circular cross-section and the pillars of one or more other rows of the plurality of rows of pillars 721-723, 731-733 may have a circular cross-section. Furthermore, the pillars of one or more rows of the plurality of rows of pillars 721-723, 731-733 may have a non-circular cross-section of a first shape and the pillars of one or more other rows of the plurality of rows of pillars 721-723, 731-733 may have a non-circular cross-section of a second shape, different to the first shape.

[0122] In another arrangement, for example in the arrangement of Figure 7c, the pillars 721-723 may have a non-circular shape which is a shape longer in a longitudinal direction than in a width direction orthogonal to the longitudinal direction. For example, the pillars 721-723 may have a rectangular cross-section, which is longer in a longitudinal direction than in a width direction.

[0123] Figure 8a provides a side cross-sectional view through the flow path defined by the fluid handling structure 12 of Figure 7c. A plan view of several pillars 721-723 arranged in the pattern of pillars 721-723 of Figure 7c and 8a is provided in Figure 8b. As shown in Figures 7c, 8a and 8b, this arrangement includes an outer row of pillars 721, a middle row of pillars 722 and an inner row of pillars 723. The inner row of pillars 723 being the row of pillars closest to the center of the space 11 and closest to the gas knife system 2, in a radial direction R of the space 11. The outer row of pillars 721 being the row of pillars farthest from the center of the space 11 and farthest from the gas knife system 2, in a radial direction of the space 11.

[0124] As shown in Figure 8a, a flow path is provided from the chamber 7 to the flow equalization structure 72 and on to the gas knife system 2. In particular, the flow path is provided from the flow equalization structure 72 to the gas supply openings 22 and gas knife openings 26. The outer row of pillars 721, middle row of pillars 722 and inner row of pillars 732 are disposed to sequentially influence a path of fluid flowing from a location radially outward of the part of the chamber 7 shown in Figure 8a to the gas knife system 2. In particular, a flow path of fluid flowing through the flow equalization structure 72 is shown by arrows 91 in Figure 8b. The pillars of the outer row of pillars 721 are arranged such that the fluid is incident on a longitudinal side of each of the pillars of the outer row of pillars 721. The fluid is then redirected from the outer row of pillars 721 towards pillars of the middle row of pillars 722. The pillars of the middle row of pillars 722 are arranged such that the fluid (re-directed from the outer row of pillars 721) is incident on a longitudinal side of each of the pillars of the middle row of pillars 722. The fluid is then redirected from the middle row of pillars 722 towards pillars of the inner row of pillars 723. The pillars of the inner row of pillars 723 are arranged such that the fluid (re-directed from the middle row of pillars 722) is incident on a longitudinal side of each of the pillars of the inner row of pillars 723. The fluid is then redirected from the inner row of pillars 721 towards the gas knife system 2, and preferably in a radial direction towards a center of the space 11.

[0125] In the arrangement of Figure 7c, similarly to the arrangement of Figure 7b, the inner row of pillars 723 may be arranged such that the channels defined between adjacent pillars of the inner row of pillars 723 direct the flow path in a radial direction towards a center of the space 11. In the arrangement of Figure 7c, the pillars of the inner row of pillars 723 may be arranged such that the longitudinal direction of the pillars 723 is a radial direction with respect to the space 11. The pillars of the inner row of pillars 723 desirably have a length (in a longitudinal direction) less than the length of the pillars of the outer row of pillars 721 and/or the middle row of pillars 722. The pillars of the inner row of pillars 723 desirably have a length of between 0.5 mm and 2 mm, more desirably between 0.5 mm and 1.5 mm, yet more desirably between 0.7 mm and 1mm.

[0126] Unlike the inner row of pillars 723 in the arrangement of Figure 7c, the pillars of the middle row of pillars 722 are arranged at an angle to the radial direction. In particular, the middle row of pillars 722 have a longitudinal direction and the longitudinal direction is at the angle to the radial direction. The pillars of the outer row of pillars 721 and the pillars of the middle row of pillars 722 may optionally be the same length. The pillars of the outer row of pillars 721 and the pillars of the middle row of pillars 722 desirably have a length greater than the length of the pillars of the inner row of pillars 723. The pillars of the outer row of pillars 721 and the pillars of the middle row of pillars 722 desirably have a length of between 0.5 mm and 5 mm, more desirably between 0.7 mm and 3 mm, yet more desirably between 1 mm and 2 mm, for example 1.5 mm. The pillars of the outer row of pillars 721, the pillars of the middle row of pillars 722 and the pillars of the inner row of pillars 723 desirably have a width of between 0.2 mm and 2 mm, more desirably between 0.3 mm and 1.5 mm, yet more desirably between 0.3 mm and 1 mm, for example 0.4 mm.

[0127] As shown in Figures 7c, 8a and 8b, the outer row of pillars 721 are arranged at an angle to the radial direction. In particular, the outer row of pillars 721 have a longitudinal direction and the longitudinal direction is at the angle to the radial direction.

[0128] The angle to the radial direction is desirably an angle of between 30° and 80°, more desirably 40° and 75°, yet more desirably 50° and 70°, yet more desirably 55° and 65°, for example 60°.

[0129] One of the outer row of pillars 721 and the middle row of pillars 722 is at the angle in a clockwise direction from the radial inward direction, and the other of the outer row of pillars 721 and the middle row of pillars 722 is at the angle in an anti-clockwise direction from the radial outward direction. For example, as shown in Figure 8b, the middle row of pillars 722 is at the angle in a clockwise direction 822 from the radially inward direction R0, and the outer row of pillars 721 is at the angle in an anti-clockwise direction 821 from the radially outward direction R1.

[0130] In the arrangement of Figures 7c, 8a and 8b the number of pillars in the outer row of pillars 721 is the same as the number of pillars in the middle row of pillars 722. The pillars in the outer row of pillars 721 are aligned with the pillars in the middle row of pillars 722 in a circumferential direction with respect to the space 11. In other words, a virtual line extending in a radial direction through a first terminal end (in a longitudinal direction) of a pillar of the outer row of pillars 721 also extends through a first terminal end of a corresponding pillar of the middle row of pillars 722. A virtual line extending in a radial direction through a second terminal end (in a longitudinal direction) of a pillar of the outer row of pillars 721 also extends through a second terminal end of a corresponding pillar of the middle row of pillars 722.

[0131] In some arrangements of the fluid handling structure 12, for example that shown in Figure 9, the flow equalization structure 70 comprises a restrictive structure 75 configured to restrict a flow path of fluid flowing from the at least one opening 51 to the gas knife system 2. The restrictive structure 75 is desirably configured to enable some fluid to pass through the restrictive structure 75 from a radially outward region to a radially inward region.

[0132] The restrictive structure 75 may take any form which restricts the flow of fluid while enabling some fluid to pass through the restrictive structure 75, such that fluid may flow from the at least one opening 51 to the gas knife system 2. As described in more detail below with reference to Figures 9 to 14, the restrictive structure 75 may define a series of openings or pores which form voids in the structure to enable fluid flow through the structure. The restrictive structure 75 may therefore have a filling ratio of solid structure volume to void volume. The filling ratio may be consistent throughout the restrictive structure 75 or may vary throughout different regions of the restrictive structure 75. The filling ratio may be selected according to the application and properties of the fluid. The voids may be arranged in a regular array/pattern or may be random. The voids of the restrictive structure 75 may all have the same size and/or shape or may be different sizes and/or shapes.

[0133] The restrictive structure 75 may, for example, comprise or consist of a 2-dimensional structure, for example a thin mesh. Alternatively, the restrictive structure 75 may, for example, comprise or consist of a 3-dimensional structure, for example a lattice structure. In some arrangements, for example the arrangements of Figures 11 to 14 as described further below, the restrictive structure 75 may comprise a plurality of tubes. The plurality of tubes may be formed of tubes of the same or different sizes and shapes. The plurality of tubes may be arranged in a regular array, or may be arranged in an irregular pattern. In some arrangements, each of the plurality of tubes may be arranged to extend in a radial direction with respect to the space 11 such that the fluid is directed towards the center of the space 11. Alternatively, the tubes may be arranged in different directions, including non-radial directions, such that the fluid may be further restricted or directed in a different direction. The restrictive structure 75 is optionally formed using additive manufacturing techniques.

[0134] In the example arrangement of Figure 9, the restrictive structure 75 is continuous and surrounds the gas knife system 2. In other words, the restrictive structure 75 of the arrangement of Figure 9 may surround the gas knife system 2 in a similar manner to the slit of the arrangement of Figure 4. The restrictive structure 75 may be a single continuous restrictive structure 75 forming a continuous circular shape around the gas knife system 2, when viewed from above, for example as shown in Figure 3. Alternatively, the restrictive structure 75 may take a continuous non-circular shape, such as a substantially diamond shape, square shape, an octagonal shape or a star shape, for example.

[0135] In the arrangement shown in Figure 9, the height of the restrictive structure 75 is equal to a height of the chamber 7. In other words, the restrictive structure 75 extends the entire height of the chamber 7. The restrictive structure 75 may extend from the floor to the ceiling of the chamber 7. In this way, the restrictive structure 75 may be configured to restrict flow of fluid from a radially outward region to a radially inward region of the chamber 7.

[0136] Figure 10 shows an alternative arrangement of the fluid handling structure 12 of Figure 4, in which the restrictive structure 75 is disposed within the at least one slit. In other words, in the arrangement of Figure 10, the restrictive structure 75 is disposed between a floor of the chamber 7 and the protruding section 121 which extends from the ceiling of the chamber 7. In an alternative arrangement, with a protruding section extending from the floor of the chamber 7, the restrictive structure 75 may be disposed between a ceiling of the chamber 7 and the protruding section. In this way, the fluid passing from a region radially outwards of the flow equalization structure 70 to a region radially inwards of the flow equalization structure 70 passes through the restrictive structure 75 disposed within the slit, or flow channel.

[0137] As described above, for example with reference to Figures 5 and 6, the flow equalization structure 71 may comprise a plurality of slits 710. The restrictive structure 75 may be disposed in a plurality of the plurality of slits 710. In other words, the restrictive structure 75 may be disposed in a space between adjacent pillars of the plurality of pillars 711 which defined the plurality of slits 710. In other words, the restrictive structure 75 desirably fills a plurality of the plurality of slits 710. More desirably, the restrictive structure 75 may fill all slits of the plurality of slits 710.

[0138] As described above, for example with reference to Figures 6b, 7a-c and 8a-b, the restrictive structure 75 may be disposed between adjacent pillars of the plurality of pillars 711, 721-723, 731-733, 741-743. The restrictive structure 75 desirably fills a space between adjacent pillars of the plurality of pillars 711, 721-723, 731-733, 741-743.

[0139] The adjacent pillars of the plurality of pillars 711, 721-723, 731-733, 741-743 may adjacent in a substantially circumferential direction with respect to the space 11. In other words, the restrictive structure 75 may be disposed between adjacent pillars of the same row of pillars 711, 721-723, 731-733, 741-743. For example, the restrictive structure 75 may be provided between adjacent pillars of an outer row of pillars 721, 731, 741 and/or an inner row of pillars 723, 733, 743 and/or middle row of pillars 722, 732, 742.

[0140] The adjacent pillars of the plurality of pillars 721-723, 731-733, 741-743 may be adjacent in a substantially radial direction with respect to the space 11. In other words, the restrictive structure 75 may be disposed between adjacent pillars of different rows of pillars 721-723, 731-733, 741-743. For example, the restrictive structure 75 may be disposed between one or more pillars of a first row of pillars 721, 731, 741 and one or more pillars of a second row of pillars 722, 732, 742, where the second row of pillars 722, 732, 742 is disposed radially inwards of the first row of pillars 721, 731, 741 with respect to the space 11. For example, in an arrangement including at least three rows of pillars 721-723, 731-733, 741-743, the restrictive structure 75 may be disposed between an outer row of pillars 721, 731, 741 and a middle row of pillars 722, 732, 742, and/or the restrictive structure 75 may be disposed between a middle row of pillars 722, 732, 742 and an inner row of pillars 723, 733, 743.

[0141] The restrictive structure 75 desirably comprises a porous member. The porous member may be a structure or material defining voids or channels through which fluid may pass. The porous member may, for example, comprise a porous material, a mesh structure, or a lattice structure. The porous member may comprise a plurality of closely-packed blocks, for example spheres, with gaps therebetween forming voids. The porous material may have a regular structure or an irregular structure. A regular structure, may be desirable such that a size of the channels/voids formed by the porous member may be known and relatively uniform around the space 11.

[0142] The restrictive structure 75 may be formed of the porous member. For example, the restrictive structure 75 may be entirely formed of a porous material. Alternatively, the restrictive structure 75 may comprise the porous material and a solid structure formed of a solid material. The solid material may be a material configured to prevent flow of fluid through the material. For example, the solid structure may be absent of voids or channels through which fluid can flow whereas the porous material provides voids or channels through which the fluid may flow on a path from a region radially outward of the flow equalization structure 70 to a region radially inwards of the flow equalization structure 70, with respect to the space 11.

[0143] Figures 11a to 14b depict example restrictive structure 75 as viewed through cross-section A-A of Figure 9. The restrictive structures 75 depicted in each of Figures 11a to 14b each comprise a plurality of tubes 750-750b. An axial direction of each tube of the plurality of tubes 750-750b desirably extends in a direction of a flow path of fluid flowing from a region radially outward of the flow equalization structure 70 to a region radially inwards of the flow equalization structure 70, with respect to the space 11. The tubes 750-750b may be arranged such that an axial, or longitudinal, direction of the tubes 750-750b extends in a substantially radial direction with respect to the space 11.

[0144] In the example restrictive structures 75 shown in Figure 11a, 12a, 13a and 14a, the porous member 751-751b is provided in an interior of each of the plurality of tubes 750-750b. In particular, in these examples, an interior of each of the plurality of tubes 750-750b is filled. For example, each of the plurality of tubes 750-750b may be filled with the porous member 751-751b. In a preferred arrangement, an interior of one or more of the plurality of tubes 750-750b, and desirably all of the tubes 750-750b, may be solid, in order to further restrict fluid flow. With the preferred arrangement, the fluid is only able to flow through gaps between the tubes 750-750b in order to reach a downstream side of the restrictive structure 75. In other words, the flow of fluid is further restricted because the fluid may not pass through the inside of the tubes 750-750b, as these are solid. In another arrangement, an interior of one or more of the plurality of tubes 750-750b, and optionally all of the tubes 750-750b, may be empty, in order to form a plurality of unrestricted flow channels through the interiors of the tubes 750-750b. With this arrangement having hollow tubes, a wall thickness of the tubes 750-750b may be sufficient to provide a solid region to restrict the fluid flow through the restrictive structure 75.

[0145] The plurality of tubes 750-750b of Figures 11a, 12a, 13a and 14a define a plurality of gaps 752-752c in the restrictive structure 75 between adjacent tubes of the plurality of tubes 750-750b. In the example restrictive structures 75 shown in Figure 11a, 12a, 13a and 14a, the plurality of gaps 752-752c are empty and form channels through which fluid may flow. Alternatively, the plurality of gaps 752-752c may be filled. In the example restrictive structures 75 shown in Figure 11b, 12b, 13b and 14b, the porous member 753-753c is provided in the plurality of gaps between adjacent tubes of the plurality of tubes 750-750b. In particular, in these examples the porous member 753-753c fills the plurality of gaps. In a preferred arrangement, an interior of one or more, and desirably all, of the plurality of gaps may be solid, in order to further restrict fluid flow. With the preferred arrangement, the fluid is only able to flow through the interior of the tubes 750-750b in order to reach a downstream side of the restrictive structure 75. In other words, the flow of fluid is further restricted because the fluid may not pass through the gaps 752-752c between the tubes 750-750b, as these are solid. In order to merely restrict, and not prevent, flow of fluid through the restrictive member 75, there should be at least some part of the structure which is not solid. In other words, it is undesirable for both all of the plurality of gaps 752-752c and the interior of all of the plurality of tubes 750-750b to be solid.

[0146] In the arrangements shown in Figures 11a-b, 13a-b and 14a-b, each of the plurality of tubes 750, 750b has a circular cross-sectional shape. In the arrangement of Figure 12, each of the plurality of tubes 750a has a non-circular cross-sectional shape. In particular, in the tubes 750a of Figure 12 have a rectangular cross-sectional shape. Alternatively, the tubes 750-750b may have a different non-circular shape, for example an elliptical shape or hexagonal shape. In another arrangement, the plurality of tubes may include tubes of different cross-sectional shapes, for example some tubes may have a circular cross-sectional shape and some tubes may have an elliptical cross-sectional shape.

[0147] In each of the arrangements shown in Figures 11a to 14b, the plurality of tubes 750-750b is arranged in an array extending in a circumferential direction with respect to the space 11. The array of tubes 750-750b of the flow equalization structure 70 may form a circular shape around the gas knife system 2, when viewed from above, for example as shown in Figure 3. Alternatively, the array of tubes 750-750b may take a continuous non-circular shape, such as a substantially diamond shape, square shape, an octagonal shape or a star shape, for example.

[0148] In the arrangements of Figures 11a-b and 12a-b, the plurality of tubes 750, 750a is arranged in a one-dimensional array extending in a circumferential direction with respect to the space 11. In the arrangements of Figures 13a-b and 14a-b, the array of the plurality of tubes 750b is a two-dimensional array. The two-dimensional array of tubes 750b of Figures 13a-b and 14a-b extends in a circumferential direction with respect to the space 11 and also extends in a height direction of the chamber 7. In this way, the arrangements of Figures 13a-b and 14a-b may comprise a greater number of smaller tubes 750b within the same cross-sectional area of the smaller number of larger tubes 750, 750a of the arrangements of Figures 11a-b and 12a-b.

[0149] The two-dimensional array of tubes 750b of Figures 13a-b and 14a-b comprises a plurality of rows of tubes 750b, each row of tubes 750b extending in a circumferential direction with respect to the space 11. In the two-dimensional array of tubes 750b of Figures 13a-b, each of the rows of tubes 750b are aligned with each other in a circumferential direction. In other words, the two-dimensional array of tubes 750b of Figures 13a-b comprises tubes 750b arranged in columns. Each column comprises a plurality of tubes 750b arranged directly above each other in a height direction of the chamber 7.

[0150] Figures 14a-b provide an example wherein the tubes 750b of adjacent rows of tubes are offset from each other in a circumferential direction. In other words, the array of tubes 750b may be arranged to from a tessellated pattern. In this way, the size of the gaps 752c between the tubes 750b of different rows may be reduced. In particular, a total cross-sectional area of the gaps 752c may be reduced comparted to the arrangement of Figures 13a-b. The array of tubes 750b of Figures 14a-b may be considered a close-packed array. Although Figures 14a-b provide an example wherein the tubes 750b have a circular cross-section to form a circular close-packed array, in an alternative arrangement there may be provided a non-circular close-packed array. For example, the restrictive structure 75 may comprise a hexagonal close-packed array, comprising a plurality of tubes 750b each having a hexagonal cross-sectional shape. The use of hexagonal cross-sectioned tubes 750b is preferable in applications where less gap 752c between the tubes 750b is desired.

[0151] The present invention may provide a lithographic apparatus. The lithographic apparatus may have any/all of the other features or components of the lithographic apparatus as described above. For example, the lithographic apparatus may optionally comprise at least one or more of a fluid handling structure 12, source SO, an illumination system IL, a projection system PS, a substrate support WT, etc.

[0152] Specifically, the lithographic apparatus may comprise the projection system PS configured to project the radiation beam B towards the region of the surface of a substrate W.

[0153] Although specific reference may be made in this text to the use of a lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. Possible other applications include the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc.

[0154] Where the context allows, embodiments of the invention may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the invention may also be implemented by instructions stored on a machine-readable medium, which may 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 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, instructions may 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. and in doing that may cause actuators or other devices to interact with the physical world.

[0155] Although specific reference may be made in this text to embodiments of the invention in the context of a lithographic apparatus, embodiments of the invention may be used in other apparatus. Embodiments of the invention may form part of a mask inspection apparatus, a metrology apparatus, or any apparatus that measures or processes an object such as a wafer (or other substrate) or mask (or other patterning device). These apparatus may be generally referred to as lithographic tools. Such a lithographic tool may use ambient (non-vacuum) conditions.

[0156] Although specific reference may have been made above to the use of embodiments of the invention in the context of optical lithography, it will be appreciated that the invention, where the context allows, is not limited to optical lithography.

[0157] Embodiments include the following numbered clauses:

1. A fluid handling structure for an immersion lithographic apparatus and configured to contain immersion fluid to a region, the fluid handling structure having, at a boundary of a space: at least one opening configured to supply the immersion fluid to the space; an extractor assembly configured to extract the immersion fluid from the space; a gas knife system radially outwards of the extractor assembly with respect to the space; a chamber upstream of the gas knife system and in fluid communication with the gas knife system, wherein the chamber comprises a flow equalisation structure such that gas flowing through the flow equalisation structure is uniform.
2. The fluid handling structure according to clause 1, wherein the gas knife system comprises at least one gas knife opening radially outwards of the extractor assembly with respect to the space.
3. The fluid handling structure according to clause 2, wherein the gas knife system comprises at least one gas supply opening radially outwards of the at least one gas knife opening relative to the space.
4. The fluid handling structure according to clause 3, further comprising a flow restriction upstream of the at least one gas supply opening such that gas exiting the at least one gas knife opening is at a higher gas velocity than gas exiting the at least one gas supply opening.
5. The fluid handling structure according to any of clauses 1-4, wherein the flow equalisation structure is configured to restrict a flow path of fluid flowing from the at least one opening to the gas knife system.

6. The fluid handling system according to clause 5, wherein the flow equalisation structure forms at least one slit with a height less than a height of the chamber adjacent to the at least one slit.

7. The fluid handling structure according to clause 6, wherein the height of the at least one slit is less than a height of the chamber directly upstream of the at least one slit and less than a height of the chamber directly downstream of the at least one slit.

8. The fluid handling structure according to any of clauses 5-7, wherein the at least one slit is a single continuous slit and surrounds the gas knife system.

9. The fluid handling structure according to any of clauses 5-7, wherein the at least one slit includes a plurality of slits.

10. The fluid handling structure according to clause 9, wherein each slit of the plurality of slits extends to direct a flow path of fluid in a radial direction with respect to the space.

11. The fluid handling structure according to clause 9 or 10, wherein each slit of the plurality of slits is disposed at a discrete location such that the plurality of slits forms a pattern of slits surrounding the gas knife system.

12. The fluid handling structure according to clause 11, wherein the pattern of slits forms a circular pattern or a square pattern or a star-shaped pattern.

13. The fluid handling structure according to any of clauses 9-12, wherein each slit of the plurality of slits is equidistant from the gas knife system in a radial direction with respect to the space.

14. The fluid handling structure according to any of clauses 9-12, wherein each slit of the plurality of slits is equidistant from a radial perimeter of the chamber in a radial direction with respect to the space.

15. The fluid handling structure according to any of clauses 9-14, wherein the majority of slits of the plurality of slits are closer to a radial perimeter of the chamber than to the gas knife system.

16. The fluid handling structure according to any of clauses 1-15, wherein the flow equalisation structure is configured to obstruct a flow path of fluid flowing from the at least one opening to the gas knife system.

17. The fluid handling structure according to clause 16, wherein the flow equalisation structure comprises a plurality of pillars, wherein the height of each pillar is equal to a height of the chamber.

18. The fluid handling structure according to clause 17, wherein the plurality of pillars comprises a plurality rows of pillars.

19. The fluid handling structure according to clause 18, wherein the plurality of rows of pillars are to direct a flow path of fluid in a radial direction with respect to the space.

20. The fluid handling structure according to clause 18 or 19, wherein the plurality of rows of pillars are arranged concentrically.

21. The fluid handling structure according to any of clauses 18-20, wherein the plurality rows of pillars are arranged in a staggered manner such that the pillars of adjacent rows are offset from each other in a circumferential direction with respect to the space.

22. The fluid handling structure according to any of clauses 18-21, wherein the plurality rows of pillars comprises an outer row of pillars and an inner row of pillars radially inwards of the outer row of pillars with respect to the space, wherein the plurality rows of pillars comprises a middle row of pillars radially inwards of the outer row of pillars, and radially outwards of the inner row of pillars.

23. The fluid handling structure according to clause 22, wherein pillars of the inner row of pillars are shorter (in a longitudinal direction) than pillars of the outer row of pillars.

24. The fluid handling structure according to clause 22 or 23, wherein the number of pillars in the inner row of pillars is greater than the number of pillars in the outer row of pillars.

25. The fluid handling structure according to clause 23 or 24, wherein pillars of the middle row of pillars are shorter than pillars of the outer row of pillars and pillars of the middle row of pillars are longer than pillars of the inner row of pillars.

26. The fluid handling structure according to any of clauses 22-25, wherein the number of pillars in the middle row of pillars is greater than the number of pillars in the outer row of pillars, and the number of pillars in the middle row of pillars is fewer than the number of pillars in the inner row of pillars.

27. The fluid handling structure according to any of clause 26, wherein the number of pillars increases exponentially from the outer row of pillars, to the middle row of pillars and to the inner row of pillars.

28. The fluid handling structure according to any of clauses 24-27, wherein the inner row of pillars are aligned with the radial direction towards the centre of the space such that fluid flowing through openings defined by the inner row of pillars is aligned with the radial direction.

29. The fluid handling structure according to any of clauses 17-28, wherein each pillar has a circular cross-section.

30. The fluid handling structure according to any of clauses 17-28, wherein each pillar has a non-circular cross-section (desirably a rectangular, elliptical or aerofoil shaped cross-section).

31. The fluid handling structure according to clause 30 when dependent on any of clauses 22-28, wherein the middle row of pillars are arranged at an angle to the radial direction towards the centre of the space.

32. The fluid handling structure according to clause 31, wherein the middle row of pillars have a longitudinal direction and the longitudinal direction is at the angle to the radial direction towards the centre of the space.

33. The fluid handling structure according to any of clauses 30-32, wherein the outer row of pillars are arranged at an angle to the radial direction towards the centre of the space.

34. The fluid handling structure according to clause 33, wherein the outer row of pillars have a longitudinal direction and the longitudinal direction is at the angle to the radial direction towards the centre of the space.

35. The fluid handling structure according to any of clauses 34, wherein the angle to the radial direction is an angle of between 30º and 80º.

36. The fluid handling structure according to clauses 35, wherein one of the outer row of pillars and the middle row of pillars is at the angle in a clockwise direction from the radial direction, and the other of the outer row of pillars and the middle row of pillars is at the angle in an anti-clockwise direction from the radial direction.

37. The fluid handling structure according to any of clauses 33-36, wherein the number of pillars in the outer row of pillars is the same as the number of pillars in the middle row of pillars.

38. The fluid handling structure according to clause 37, wherein the pillars in the outer row of pillars are aligned with the pillars in the middle row of pillars in a circumferential direction with respect to the space.

39. The fluid handling structure according to any one of clauses 5 to 38, wherein the flow equalisation structure comprises a restrictive structure configured to restrict a flow path of fluid flowing from the at least one opening to the gas knife system.

40. The fluid handling structure according to clause 39, wherein the restrictive structure is continuous and surrounds the gas knife system.

41. The fluid handling structure according to clause 39 or 40, wherein the height of the restrictive structure is equal to the height of the chamber.

42. The fluid handling structure according to clause 39 when dependent on any one of clauses 6 to 15, wherein the restrictive structure is disposed within the at least one slit.

43. The fluid handling structure according to clause 42, wherein the restrictive structure fills the at least one slit.

44. The fluid handling structure according to clause 42 or 43, wherein the at least one slit comprises all slits of the plurality of slits.

45. The fluid handling structure according to clause 39 when dependent on any one of clauses 17 to 38, wherein the restrictive structure is disposed between adjacent pillars of the plurality of pillars.

46. The fluid handling structure according to clause 45, wherein the restrictive structure fills a space between adjacent pillars of the plurality of pillars.

47. The fluid handling structure according to clause 45 or 46, wherein the adjacent pillars of the plurality of pillars are adjacent in a circumferential direction with respect to the space.

48. The fluid handling structure according to any one of clauses 45 to 47, wherein the adjacent pillars of the plurality of pillars are adjacent in a radial direction with respect to the space.

49. The fluid handling structure according to any one of clauses 39 to 48, wherein the restrictive structure comprises a porous member.

50. The fluid handling structure according to clause 49, wherein the porous member comprises:

a porous material; or

a mesh structure; or

a lattice structure.

51. The fluid handling structure according to clause 49 or 50, wherein the restrictive structure is formed of the porous member.

52. The fluid handling structure according to any one of clauses 39 to 50, wherein the restrictive structure comprises a plurality of tubes, wherein an axial direction of the tubes extends in a substantially radial direction with respect to the space.

53. The fluid handling structure according to clause 52 when dependent on clause 49 or 50, wherein the porous member is provided in an interior of each of the plurality of tubes.

54. The fluid handling structure according to clause 53, wherein the porous member fills the interior of each of the plurality of tubes.

55. The fluid handling structure according to clause 52, wherein an interior of each of the plurality of tubes is solid.

56. The fluid handling structure according to any one of clauses 52 to 55, wherein each of the plurality of tubes has a non-circular cross-sectional shape.

57. The fluid handling structure according to any one of clauses 52 to 56, wherein the plurality of tubes is arranged in an array extending in a circumferential direction with respect to the space.

58. The fluid handling structure according to clause 57, wherein the array of the plurality of tubes is a two-dimensional array.

59. The fluid handling structure according to any one of clauses 52 to 58, the plurality of tubes defines a plurality of gaps in the restrictive structure between adjacent tubes.

60. The fluid handling structure according to clause 59, wherein the porous member is provided in the plurality of gaps.

61. The fluid handling structure according to clause 60, wherein the porous member fills the plurality of gaps.

62. The fluid handling structure according to clause 59, wherein a solid material fills the plurality of gaps.

63. A lithographic apparatus comprising the fluid handling structure according to any of the preceding clauses.

64. A method of manufacturing the fluid handling structure handling structure according to any of the preceding clauses, wherein the method comprises additive manufacturing.

[0158] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

CLAIMS

1. A fluid handling structure for an immersion lithographic apparatus and configured to contain immersion fluid to a region, the fluid handling structure having, at a boundary of a space:

at least one opening configured to supply the immersion fluid to the space;

an extractor assembly configured to extract the immersion fluid from the space;

a gas knife system radially outwards of the extractor assembly with respect to the space;

a chamber upstream of the gas knife system and in fluid communication with the gas knife system,

wherein the chamber comprises a flow equalisation structure such that gas flowing through the flow equalisation structure is uniform.

2. The fluid handling structure according to claim 1, wherein the gas knife system comprises at least one gas knife opening radially outwards of the extractor assembly with respect to the space, desirably wherein the gas knife system comprises at least one gas supply opening radially outwards of the at least one gas knife opening relative to the space, desirably further comprising a flow restriction upstream of the at least one gas supply opening such that gas exiting the at least one gas knife opening is at a higher gas velocity than gas exiting the at least one gas supply opening.

3. The fluid handling structure according to claim 1 or 2, wherein the flow equalisation structure is configured to restrict a flow path of fluid flowing from the at least one opening to the gas knife system, desirably wherein the flow equalisation structure forms at least one slit with a height less than a height of the chamber adjacent to the at least one slit, desirably wherein the height of the at least one slit is less than a height of the chamber directly upstream of the at least one slit and less than a height of the chamber directly downstream of the at least one slit.

4. The fluid handling structure according to claim 3, wherein the at least one slit is a single continuous slit and surrounds the gas knife system, or wherein the at least one slit includes a plurality of slits, desirably wherein each slit of the plurality of slits extends to direct a flow path of fluid in a radial direction with respect to the space, desirably wherein each slit of the plurality of slits is disposed at a discrete location such that the plurality of slits forms a pattern of slits surrounding the gas knife system, desirably wherein the pattern of slits forms a circular pattern or a square pattern or a star-shaped pattern.

5. The fluid handling structure according to claim 4, wherein each slit of the plurality of slits is equidistant from the gas knife system in a radial direction with respect to the space, or wherein each slit of the plurality of slits is equidistant from a radial perimeter of the chamber in a radial direction

with respect to the space, desirably wherein the majority of slits of the plurality of slits are closer to a radial perimeter of the chamber than to the gas knife system.

6. The fluid handling structure according to any of claims 1-5, wherein the flow equalisation structure is configured to obstruct a flow path of fluid flowing from the at least one opening to the gas knife system, desirably wherein the flow equalisation structure comprises a plurality of pillars, wherein the height of each pillar is equal to a height of the chamber, desirably wherein the plurality of pillars comprises a plurality rows of pillars, desirably wherein the plurality of rows of pillars are to direct a flow path of fluid in a radial direction with respect to the space, desirably wherein the plurality of rows of pillars are arranged concentrically.

7. The fluid handling structure according to claim 6, wherein the plurality rows of pillars are arranged in a staggered manner such that the pillars of adjacent rows are offset from each other in a circumferential direction with respect to the space, and/or wherein the plurality rows of pillars comprises an outer row of pillars and an inner row of pillars radially inwards of the outer row of pillars with respect to the space, the plurality rows of pillars comprises a middle row of pillars radially inwards of the outer row of pillars, and radially outwards of the inner row of pillars, desirably wherein pillars of the inner row of pillars are shorter (in a longitudinal direction) than pillars of the outer row of pillars, desirably wherein the number of pillars in the inner row of pillars is greater than the number of pillars in the outer row of pillars, desirably wherein pillars of the middle row of pillars are shorter than pillars of the outer row of pillars and pillars of the middle row of pillars are longer than pillars of the inner row of pillars, desirably wherein the number of pillars in the middle row of pillars is greater than the number of pillars in the outer row of pillars, and the number of pillars in the middle row of pillars is fewer than the number of pillars in the inner row of pillars, desirably wherein the number of pillars increases exponentially from the outer row of pillars, to the middle row of pillars and to the inner row of pillars, desirably wherein the inner row of pillars are aligned with the radial direction towards the centre of the space such that fluid flowing through openings defined by the inner row of pillars is aligned with the radial direction.

8. The fluid handling structure according to claim 6- or 7, wherein each pillar has a circular cross-section, or wherein each pillar has a non-circular cross-section (desirably a rectangular, elliptical or aerofoil shaped cross-section), desirably when dependent on claim 7, wherein the middle row of pillars are arranged at an angle to the radial direction towards the centre of the space, desirably wherein the middle row of pillars have a longitudinal direction and the longitudinal direction is at the angle to the radial direction towards the centre of the space.

9. The fluid handling structure according to claim 8, wherein the outer row of pillars are arranged at an angle to the radial direction towards the centre of the space, desirably wherein the outer row of pillars have a longitudinal direction and the longitudinal direction is at the angle to the radial direction towards the centre of the space, desirably wherein the angle to the radial direction is an angle of between 30° and 80°, desirably wherein one of the outer row of pillars and the middle row of pillars is at the angle in a clockwise direction from the radial direction, and the other of the outer row of pillars and the middle row of pillars is at the angle in an anti-clockwise direction from the radial direction, desirably wherein the number of pillars in the outer row of pillars is the same as the number of pillars in the middle row of pillars, desirably wherein the pillars in the outer row of pillars are aligned with the pillars in the middle row of pillars in a circumferential direction with respect to the space.

10. The fluid handling structure according to any of claims 3-9, wherein the flow equalisation structure comprises a restrictive structure configured to restrict a flow path of fluid flowing from the at least one opening to the gas knife system, desirably wherein the restrictive structure is continuous and surrounds the gas knife system, desirably wherein the height of the restrictive structure is equal to the height of the chamber, desirably when dependent on any of claims 3-5, wherein the restrictive structure is disposed within the at least one slit, desirably wherein the restrictive structure fills the at least one slit, desirably wherein the at least one slit comprises all slits of the plurality of slits.

11. The fluid handling structure according to claim 10 when dependent on any of claims 6-9, wherein the restrictive structure is disposed between adjacent pillars of the plurality of pillars, desirably wherein the restrictive structure fills a space between adjacent pillars of the plurality of pillars, desirably wherein the adjacent pillars of the plurality of pillars are adjacent in a circumferential direction with respect to the space, desirably wherein the adjacent pillars of the plurality of pillars are adjacent in a radial direction with respect to the space, desirably wherein the restrictive structure comprises a porous member, desirably wherein the porous member comprises: a porous material; or a mesh structure; or a lattice structure, desirably wherein the restrictive structure is formed of the porous member.

12. The fluid handling structure according to claim 10 or 11, wherein the restrictive structure comprises a plurality of tubes, wherein an axial direction of the tubes extends in a substantially radial direction with respect to the space, desirably when dependent on claim 11, wherein the porous member is provided in an interior of each of the plurality of tubes, desirably wherein the porous member fills the interior of each of the plurality of tubes, desirably wherein an interior of each of the plurality of tubes is solid.

13. The fluid handling structure according to claim 12, wherein each of the plurality of tubes has a non-circular cross-sectional shape, and/or wherein the plurality of tubes is arranged in an array extending in a circumferential direction with respect to the space, desirably wherein the array of the plurality of tubes is a two-dimensional array, and/or wherein the plurality of tubes defines a plurality of gaps in the restrictive structure between adjacent tubes, desirably wherein the porous member is provided in the plurality of gaps, desirably wherein the porous member fills the plurality of gaps, desirably wherein a solid material fills the plurality of gaps.

14. A lithographic apparatus comprising the fluid handling structure according to any of the preceding claims.

15. A method of manufacturing the fluid handling structure handling structure according to any of claims 1-13, wherein the method comprises additive manufacturing.

Fig. 1

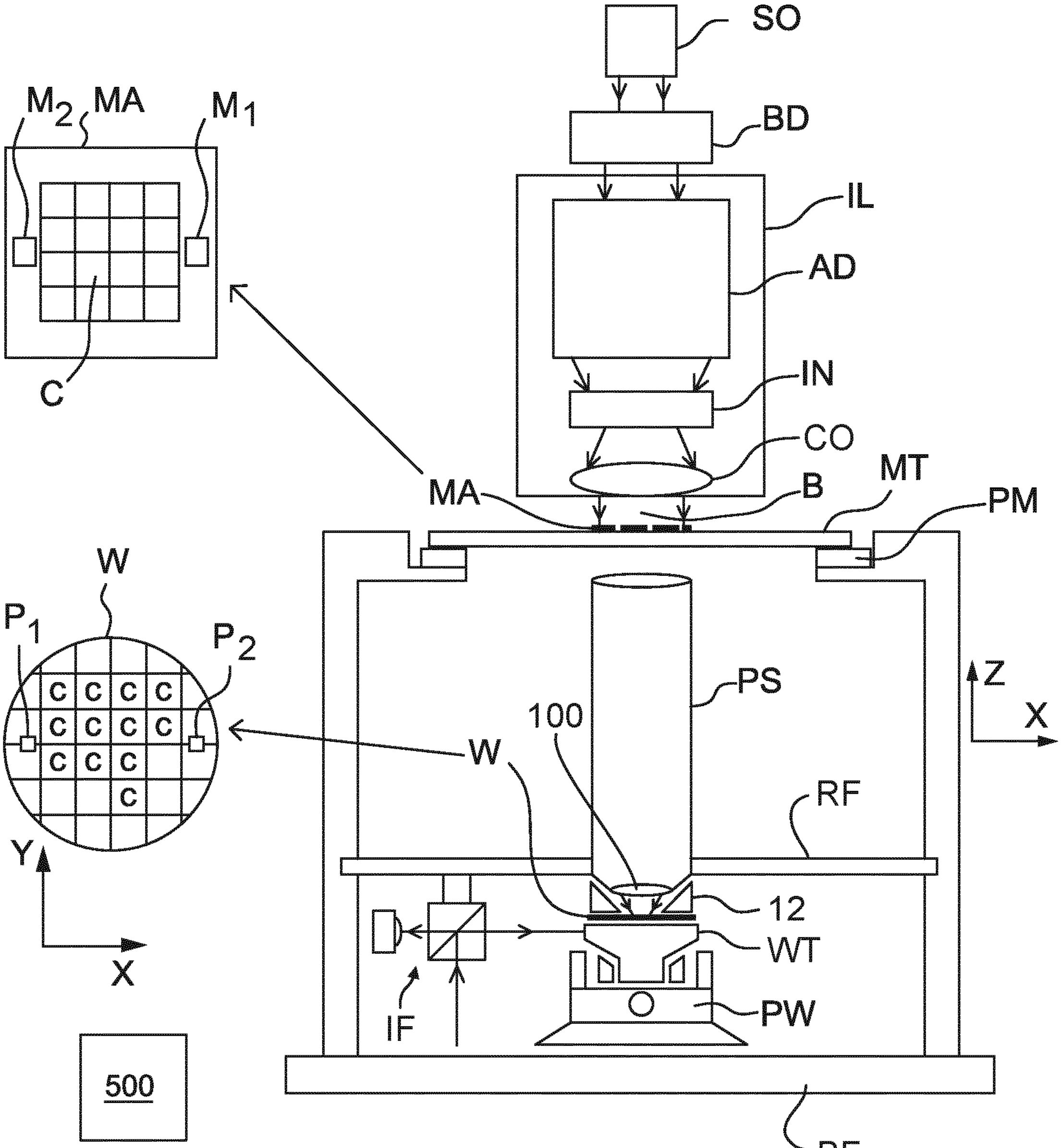
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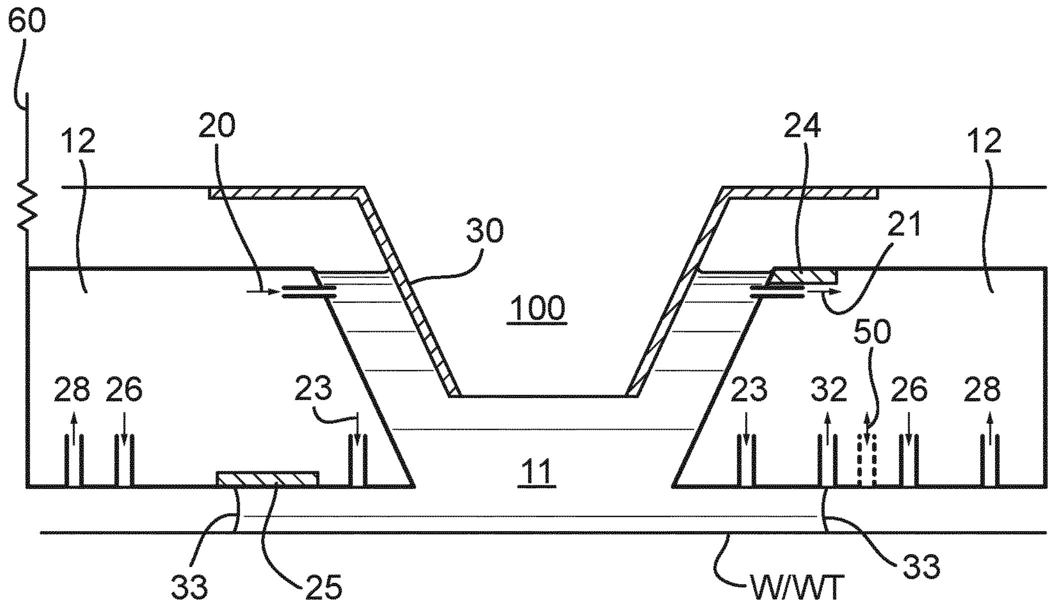
Fig. 2a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50
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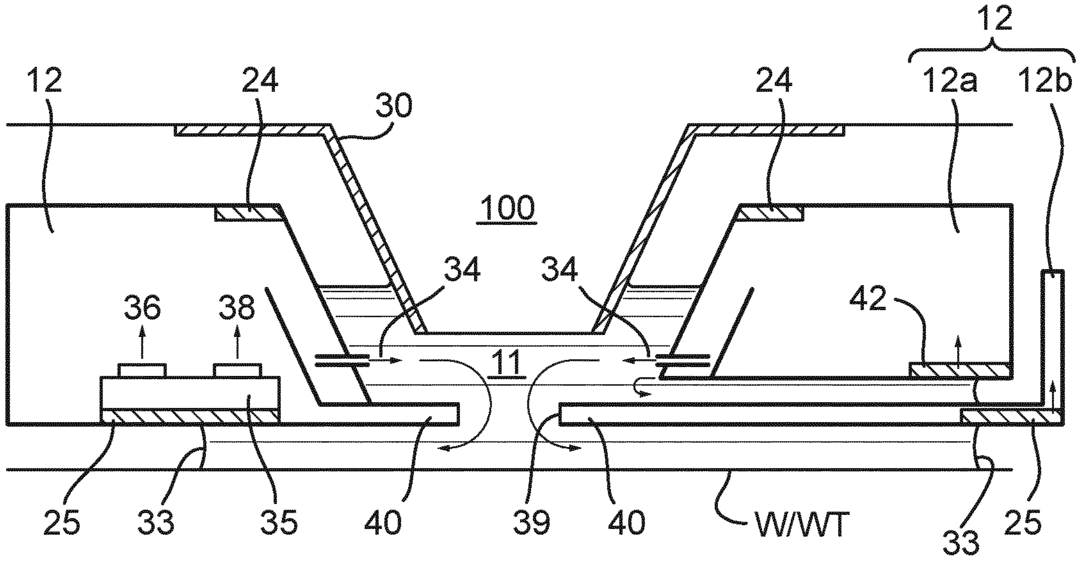
26
23
23
32
26
28
11
33
25
W/WT
33

Fig. 2b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12
24
30
24
12a
12b
100
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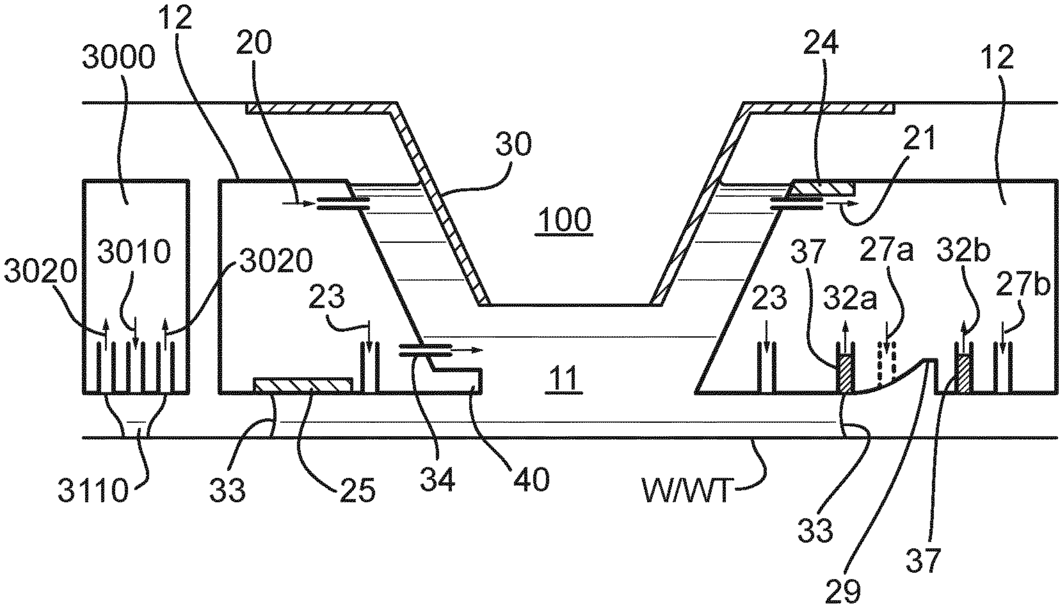
34
36
38
42
11
25
33
35
40
39
40
W/WT
33
25

Fig. 2c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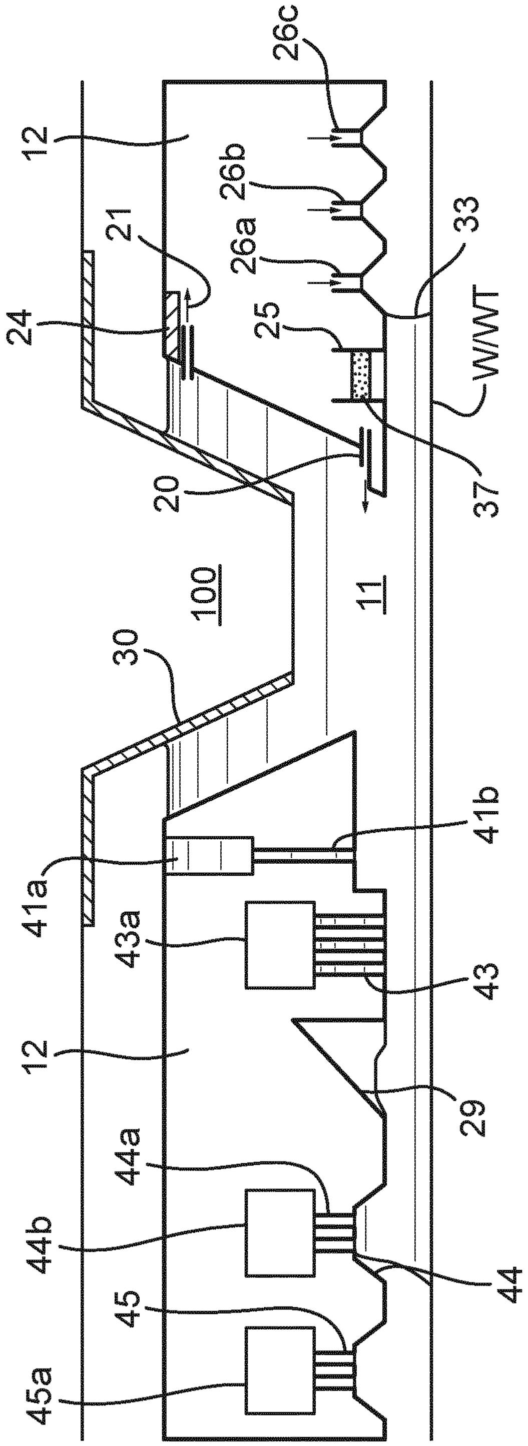
25
34
40
W/WT
33
37
29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12
29
44a
44b
44
45
45a

Fig. 2d

Fig. 3

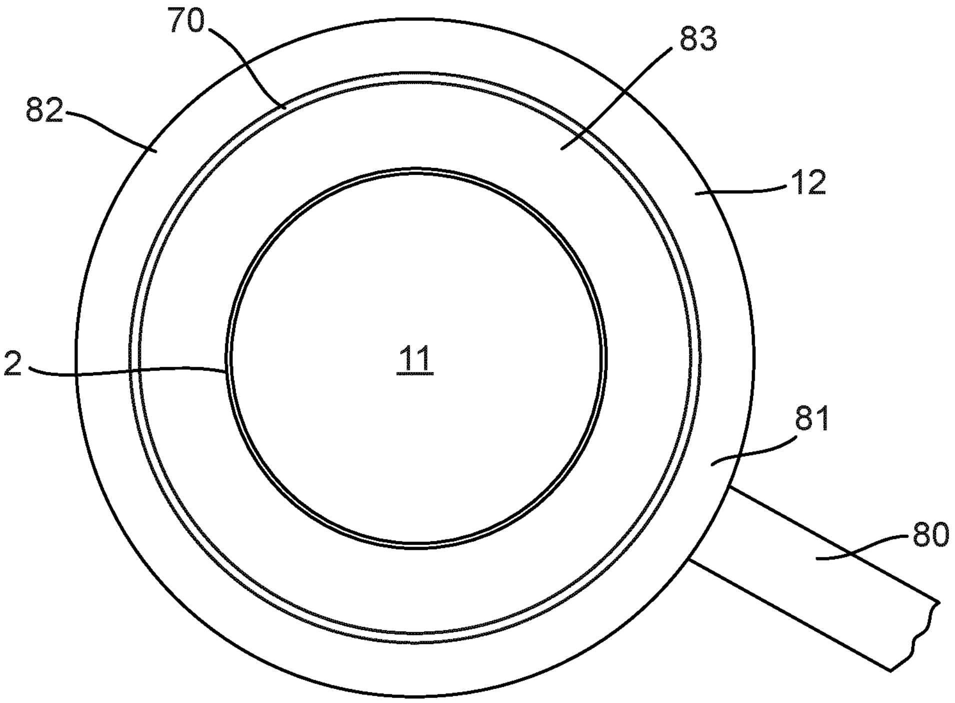


Fig. 4

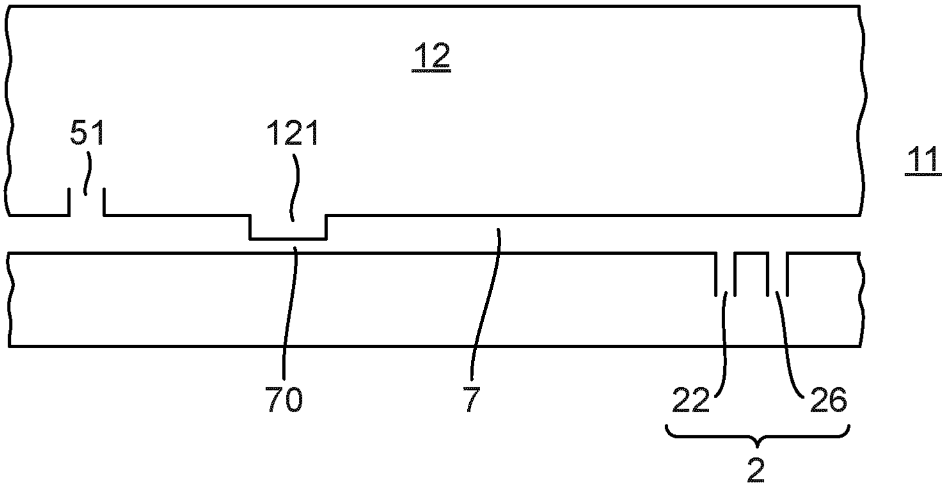


Fig. 5

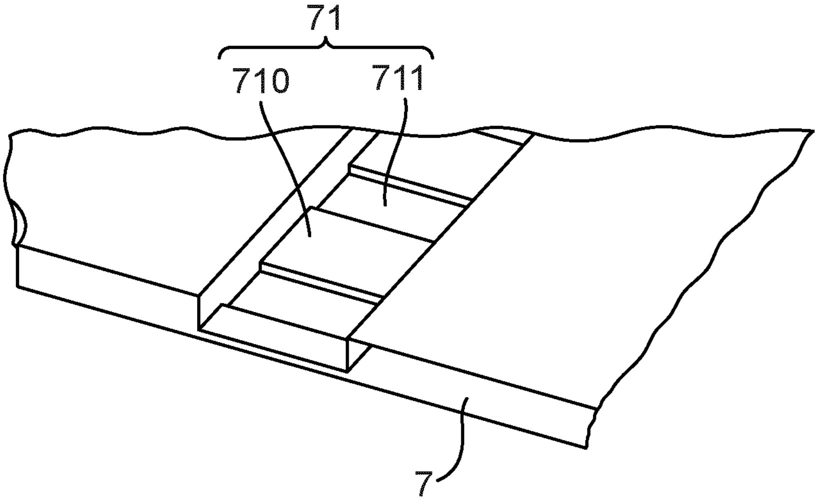


Fig. 6a

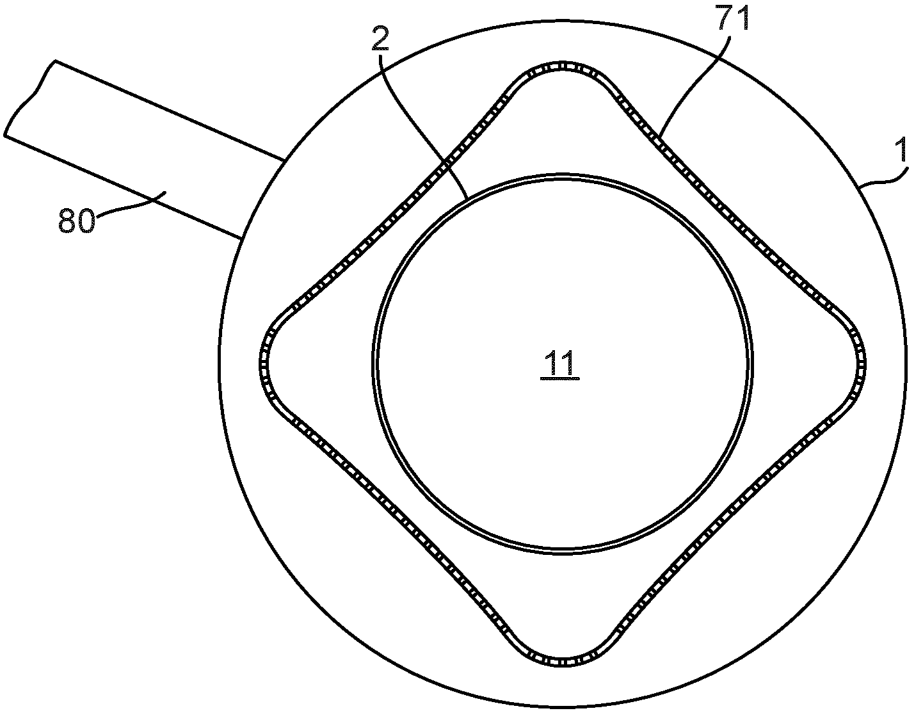


Fig. 6b

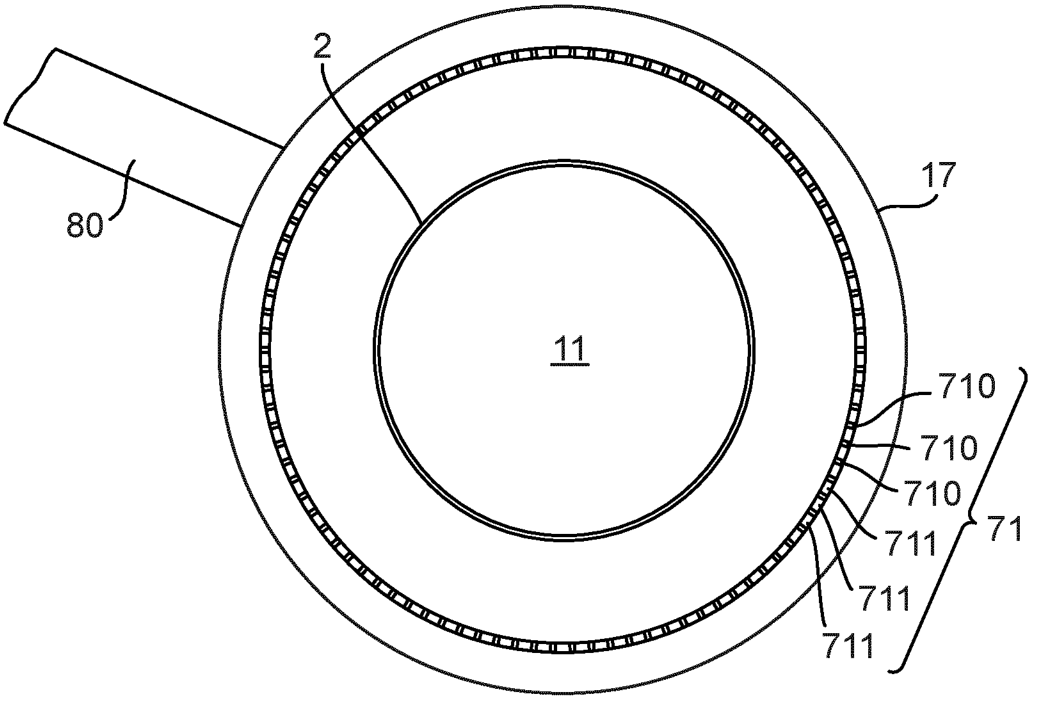


Fig. 7a

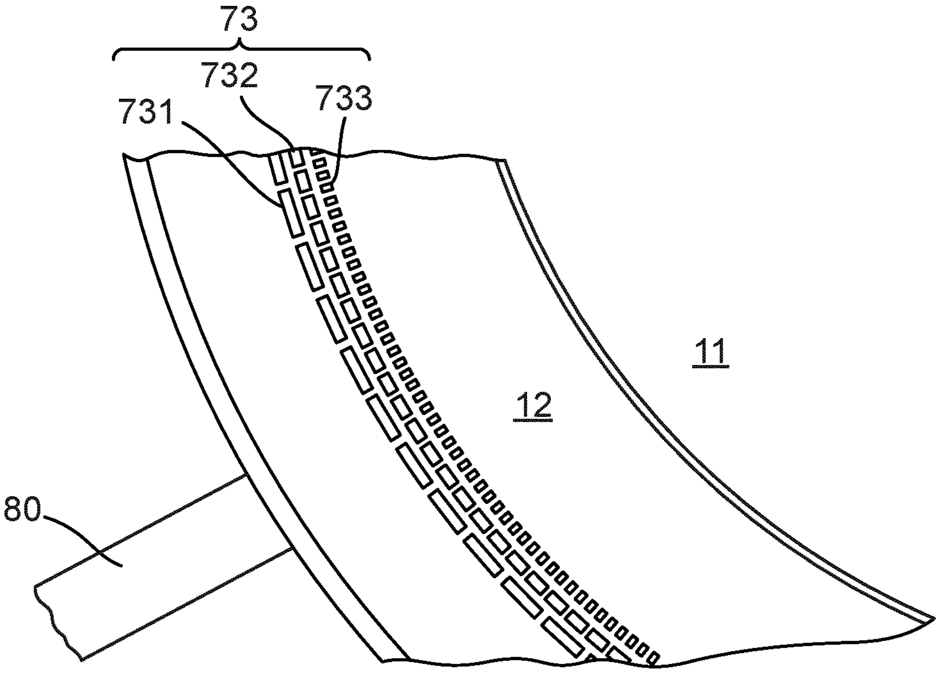


Fig. 7b

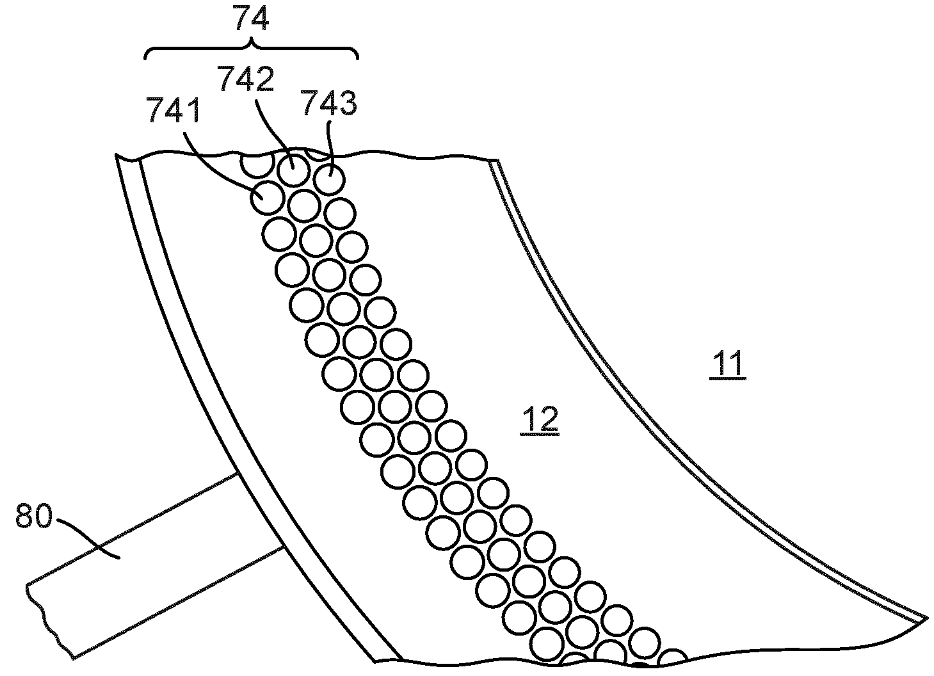


Fig. 7c

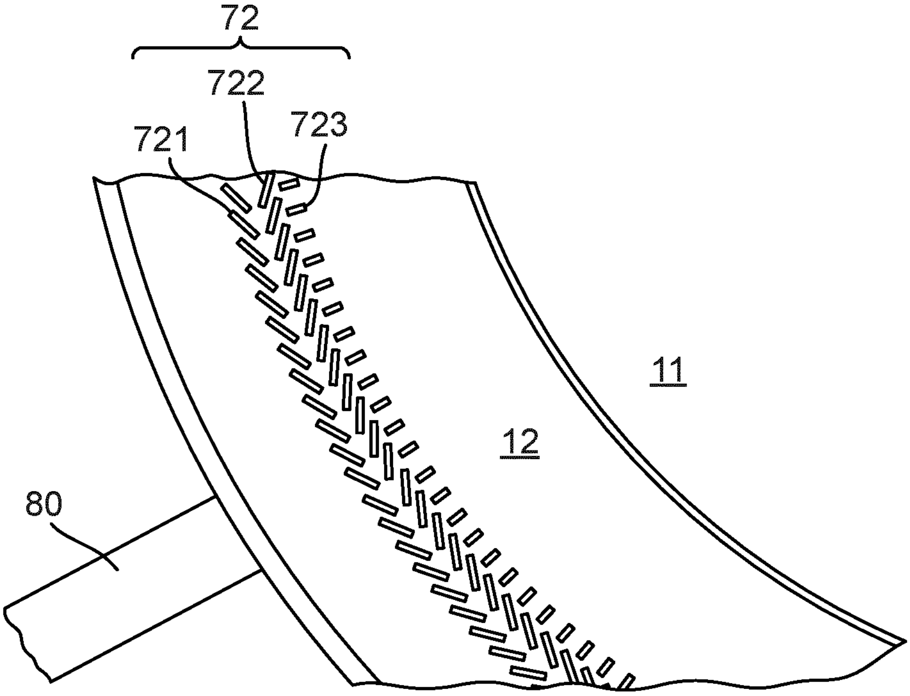


Fig. 8a

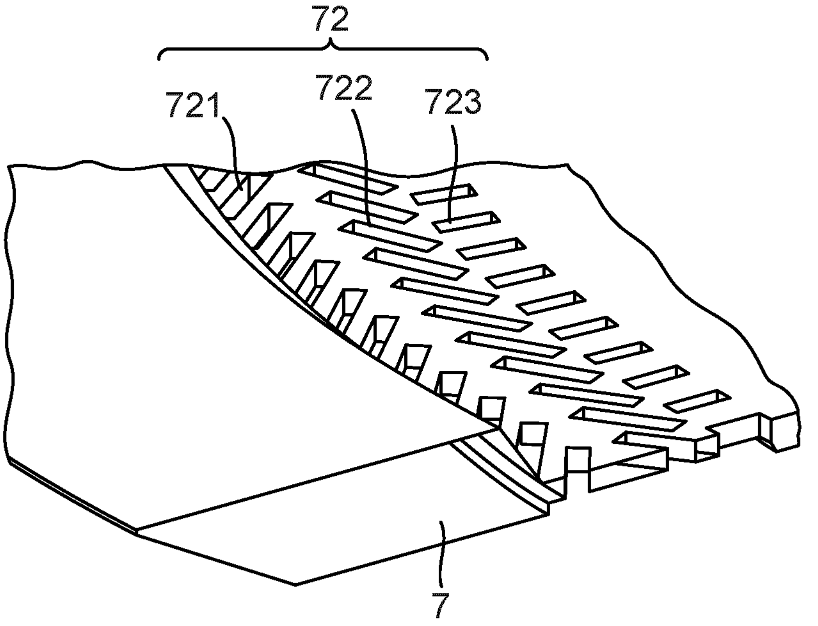


Fig. 8b

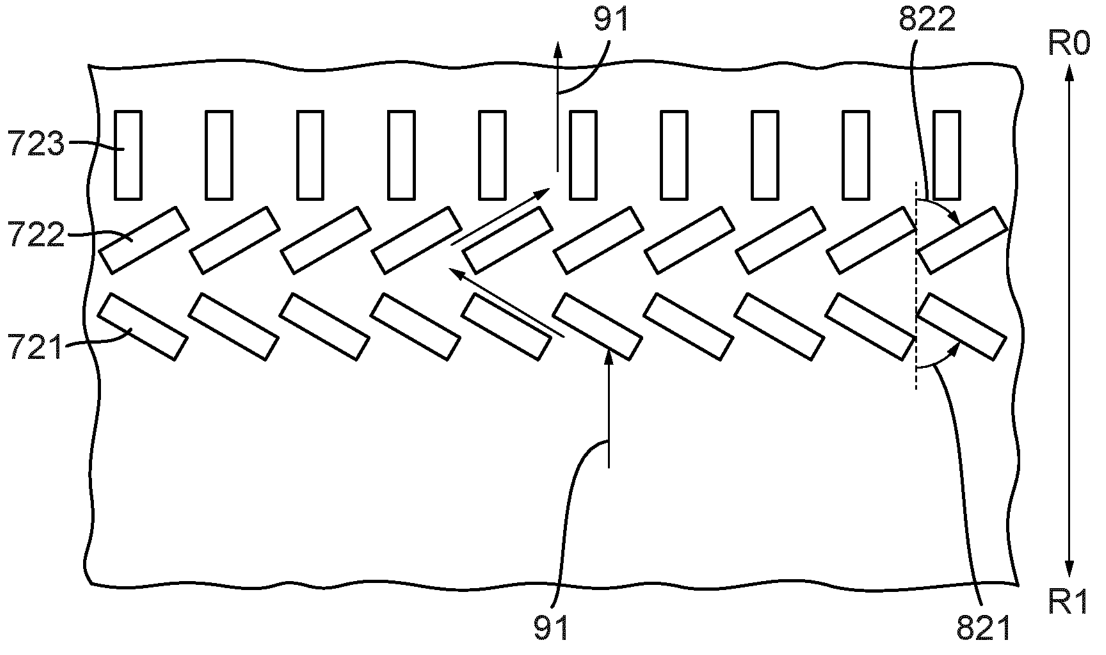


Fig. 9

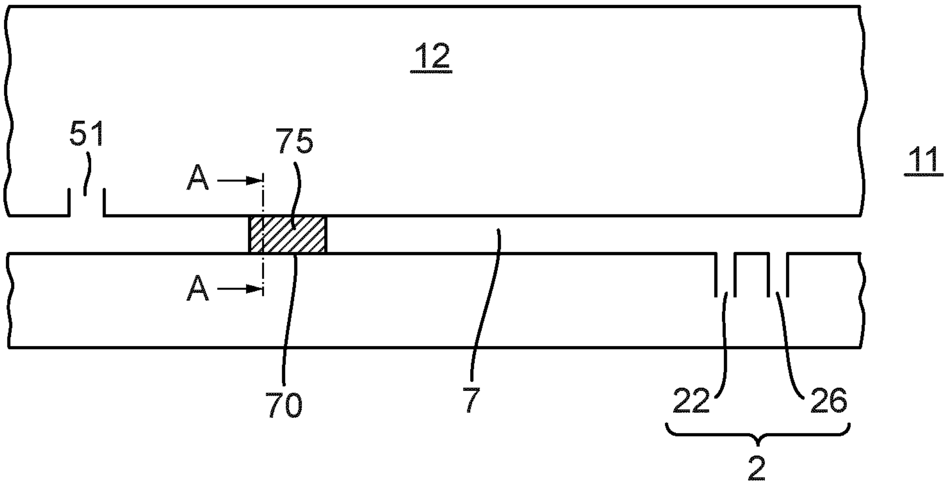


Fig. 10

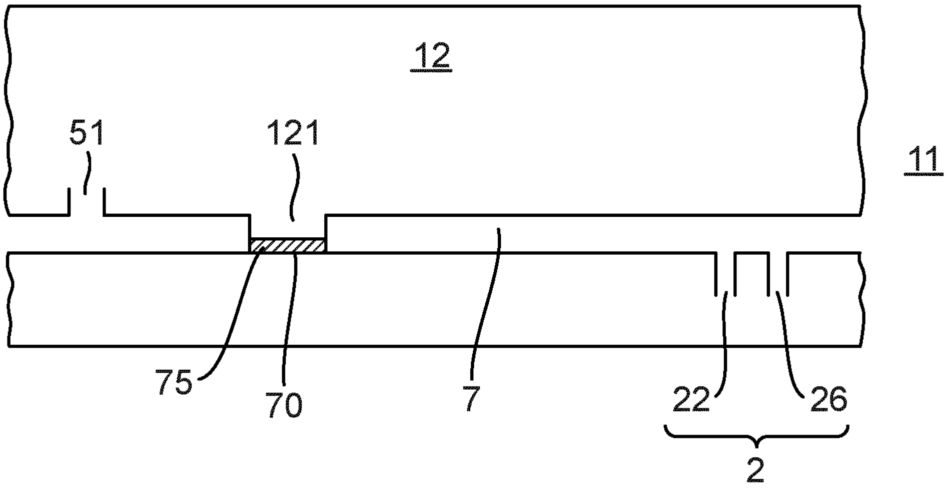


Fig. 11a

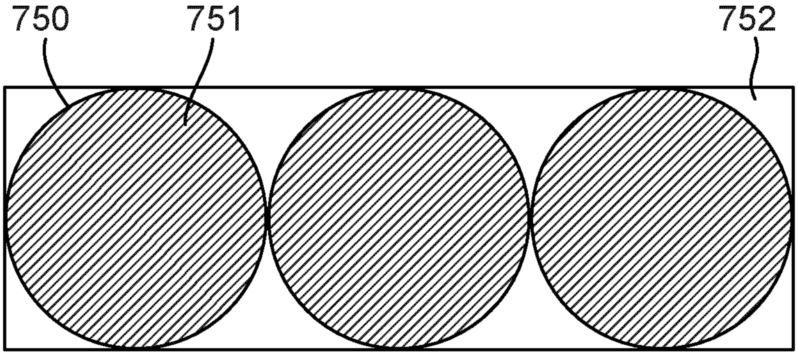


Fig. 11b

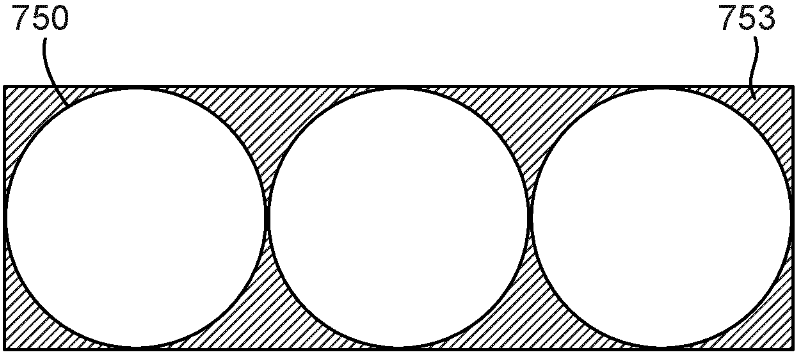


Fig. 12a

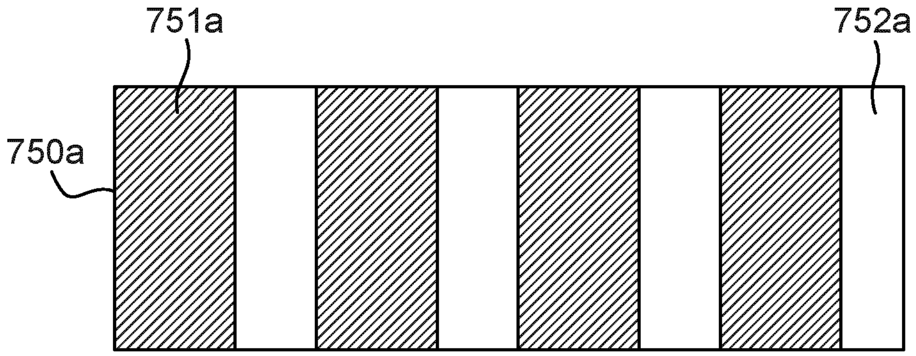


Fig. 12b

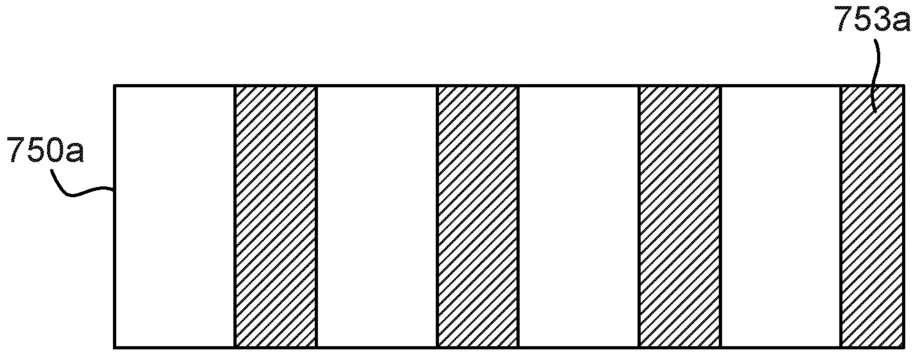


Fig. 13a

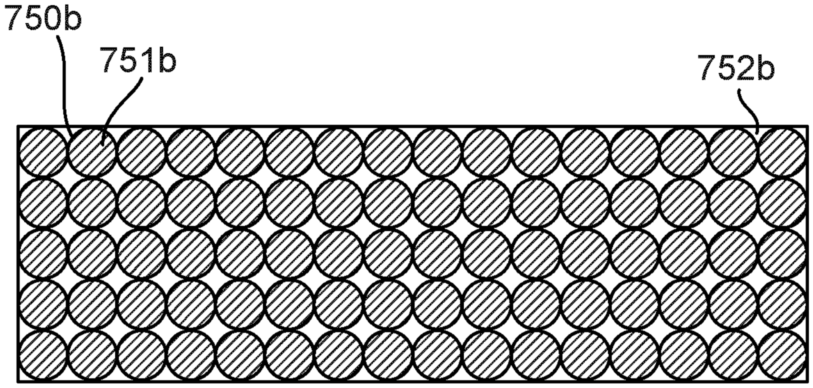


Fig. 13b

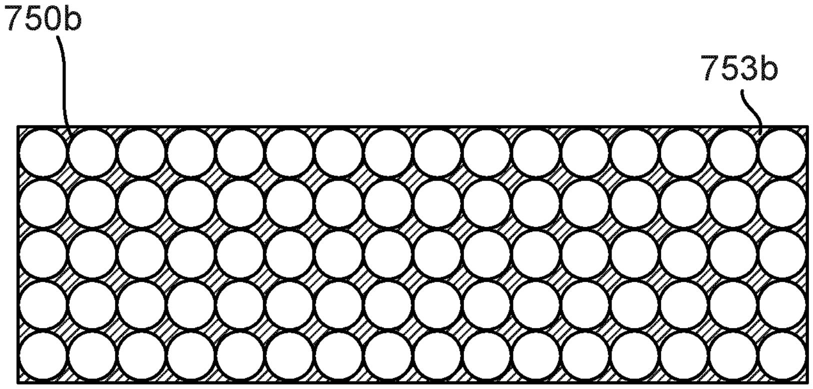


Fig. 14a

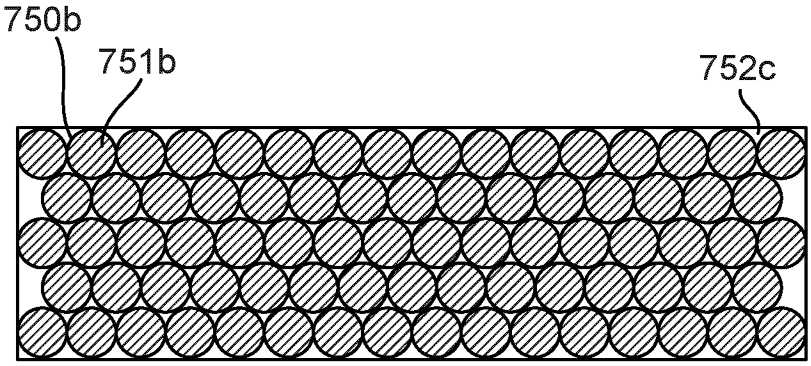
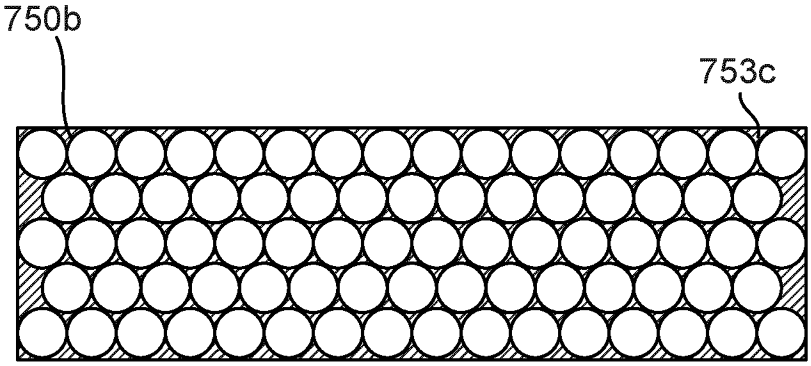


Fig. 14b



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/053126

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2021/088912 A1 (ROPS CORNELIUS MARIA [NL] ET AL) 25 March 2021 (2021-03-25) paragraphs [0063] - [0067], [0084], [0112], [0113], [0118] - [0120]; figures 1,4,11 -----	1-4,6, 10,14,15
X	US 2007/252964 A1 (KOHNO HIROTAKA [JP] ET AL) 1 November 2007 (2007-11-01) paragraphs [0106] - [0112], [0124], [0125]; figures 1,2,7 -----	1,14,15
A	WO 2022/218616 A1 (ASML NETHERLANDS BV [NL]) 20 October 2022 (2022-10-20) the whole document -----	1-15

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

☒ See patent family annex.

* Special categories of cited documents :

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/053126

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2021088912 A1	25-03-2021	CN 107106938 A	29-08-2017
		CN 110286567 A	27-09-2019
		JP 2017538159 A	21-12-2017
		KR 20170097162 A	25-08-2017
		KR 20190137176 A	10-12-2019
		NL 2015915 A	20-09-2016
		TW 201632241 A	16-09-2016
		US 2017363948 A1	21-12-2017
		US 2020166851 A1	28-05-2020
		US 2021088912 A1	25-03-2021
		WO 2016096508 A1	23-06-2016
US 2007252964 A1	01-11-2007	NONE	
WO 2022218616 A1	20-10-2022	CN 117178232 A	05-12-2023
		EP 4323841 A1	21-02-2024
		JP 2024514056 A	28-03-2024
		KR 20230169991 A	18-12-2023
		TW 202248763 A	16-12-2022
		WO 2022218616 A1	20-10-2022