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(54) **DROPLET GENERATOR**

(57) There is provided a droplet generator comprising: a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction; a plurality of piezo elements (17) at least partially surrounding the conduit, characterized in that at least one of the piezo elements in configured to operate in shear mode such that shear motion of the at least one piezo element is in the molten target material direction.

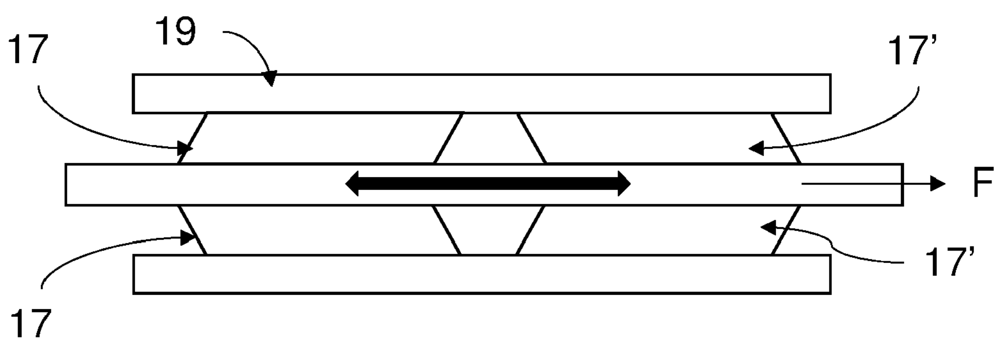

FIG. 4

EP 4 465 768 A1

Description

FIELD

[0001] The present disclosure relates to a droplet generator in particular, but not exclusively, for the generation of EUV light. The droplet generator can be used in connection with a lithographic apparatus, particularly, but not exclusively, an EUV lithography apparatus. The present disclosure also relates to an assembly for a lithography apparatus including such a droplet generator, and a lithography apparatus including such a droplet generator or assembly. In addition, the present disclosure relates to a method of generating a stream of molten target material droplets, as well as the use of such a droplet generator, assembly, lithography apparatus, or method in a lithography method or apparatus.

BACKGROUND

[0002] 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 at a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0003] 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 can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

[0004] Methods for generating EUV light include, but are not limited to, altering the physical state of a source material, also known as a target material, to a plasma state. The source materials include a compound or an element, for example, xenon, lithium, or tin, with an emission line in the EUV range. In one such method, often termed laser produced plasma ("LPP"), the required plasma is produced by irradiating a source material, for example, in the form of a droplet, stream, or cluster of source material, with an amplified light beam that can be referred to as a drive laser. For this process, the plasma is typically produced in a sealed vessel, for example, a vacuum chamber. Where droplets are used, they are provided via a droplet generator apparatus, which is supplied with high pressure liquid source material.

[0005] As lithography apparatuses advance, existing assemblies used in such apparatuses will not have the required performance, stability, or reliability required. Existing droplet generators will be unable to meet the requirements of next generation lithography apparatuses, which will likely require higher frequencies, and so it is desirable to provide apparatuses and assemblies which provide improved performance, stability, and/or reliability.

SUMMARY

[0006] According to a first aspect there is provided a droplet generator comprising: a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, characterized in that at least one of the piezo elements is configured to operate in shear mode such that shear motion of the at least one piezo element is in the molten target material direction.

[0007] Piezoelectric materials generate an internal strain resulting from an applied electric field and *vice versa.* As such, it is possible to control the deformation of a piezoelectric material by application of an electric field. Piezoelectric elements are used in inkjet printers for deforming a side wall of a chamber containing an ink to squeeze the ink out of an outlet. There are chambers adjacent to one another which share a common wall including a piezoelectric material such that when the wall is deformed in one direction, the associated chamber is squeezed and the adjacent chamber is refilled with ink. Such printers rely on changes in volume, and therefore pressure, to expel ink droplets. If the piezoelectric material is not activated by the application of an electric field, the ink will remain in the chambers.

[0008] In existing droplet generators for lithography apparatuses, a radially poled piezo cylinder is provided around a capillary. The piezo cylinder is configured such that it excites molten target material flowing through the capillary in the acoustic frequency region via the so-called d33 and d31 modes of the piezo material. Such modes are in the thickness and length direction of the piezo cylinder. In such modes, the polarization and electric field are aligned. When molten target material is flow through the capillary, the flow is disrupted by the deformations of the piezoelectric material at least partially surrounding the capillary, causing it to split into droplets. Without deformation of the piezoelectric material, there would be a continuous stream of molten target material leaving the orifice.

[0009] In d15 mode, also referred to as shear mode, the electric field is perpendicular to polarization. This allows for a greater potential difference to be provided, which can be provided as either a positive or negative voltage, since the polarization is perpendicular to the applied field and is therefore less likely to be flipped by the application of an electric field. This allows an increase in sensitivity and therefore improved performance. Furthermore, the use of a shear mode in the same direction as the direction of the molten target material through the conduit results in the generation of droplets via perturbation of velocity rather than pressure, which also improves performance and reliability, particularly at higher frequencies. It will be appreciated that the plurality of piezo elements may at least partially or completely surround the conduit. As such, there may be portions around the circumference of the conduit which are not surrounded by a piezo element. For example, in some embodiments, the piezo elements may be distributed around the circumference of the conduit and be circumferentially spaced apart. In other embodiments, the piezo elements are arranged to completely surround the conduit without being circumferentially spaced apart from one another. Furthermore, it will be appreciated that the plurality of piezo elements do not necessarily extend the full length of the conduit. An advantage of having a piezo element which does not completely surround the conduit is that it is easier to provide an electrode on an internal surface of the piezo element. When the piezo element is a complete tube, it is more difficult or even impossible to create complex electrode patterns, such as interdigitated patterns. With a segmented piezo element, it is readily possible to create such complex electrode patterns.

[0010] The conduit may be a capillary. In lithography apparatuses, only a small amount of molten target material is needed to generate the light of a desired wavelength, so a capillary is sufficient to provide the molten target material.

[0011] The conduit may be a glass capillary. Since the molten target material, such as tin, may be corrosive in its molten form to metals, it is preferable to use a material which is stable to exposure to the molten target material.

[0012] The droplet generator may further include a controller configured to control voltage applied to the piezo elements. The controller may be configured to control the magnitude, frequency, and duty cycle of the voltage applied to the piezo elements in order to control the generation of droplets of the molten target material.

[0013] At least one of the piezo elements includes segmented electrodes. These may be provided via application of a mask during deposition of the electrode or could be machined away after deposition. The use of segmented electrodes allows for improved performance since it is possible to individually control segments of the electrodes, thereby allowing for increased sensitivity.

[0014] The segmented electrodes may be interdigitated. By interdigitating the electrodes, it is possible to alternate poling along the conduit. As such, in embodiments, the piezo elements are arranged such that poling is alternated along the conduit.

[0015] At least one of the segmented electrodes may extend from an internal face of a piezo element to an external face of a piezo element. In this way, the number of connections required to control the piezo elements is reduced, thereby simplifying the apparatus.

[0016] The droplet generator may include a pre-load tube at least partially surrounding the plurality of piezo elements. Since the piezo elements are configured to apply a force to the conduit, an equal and opposite force is provided by the conduit to the piezo elements. This could lead to the piezo elements moving away from the conduit rather than exerting the force on the conduit. The pre-load tube constrains the piezo elements such that they are not able to move away from the conduit and thereby apply more of the force generated to the conduit. Again, it will be appreciated that the pre-load tube may partially or completely surround the plurality of piezo elements. Similarly, the pre-load tube may partially or completely extend along the axial length of the piezo elements.

[0017] The droplet generator may be configured to provide a positive or negative potential difference to the plurality of piezo elements. Since the piezo elements are configured to shear in the direction of the molten target material, it is possible to provide a positive or a negative potential difference. In other modes, only a positive potential difference may be applied in order to avoid the problem of polarization being flipped.

[0018] A gap may be provided between adjacent piezo elements. Preferably, the gap is in the longitudinal axis of the conduit. Since the piezo elements are operated in shear mode in the same direction as the flow of molten target material, a gap may avoid adjacent piezo elements from applying a force to one another in operation.

[0019] The molten target material may be a liquid metal. The metal is preferably tin or lithium.

[0020] According to a second aspect of the present disclosure, there is provided an assembly for a lithography apparatus including the droplet generator according to the first aspect of the present disclosure.

[0021] The assembly may be a droplet generator apparatus for a lithography apparatus, preferably an EUV lithography apparatus.

[0022] The assembly may include a molten target material reservoir, such as a molten tin reservoir.

[0023] The assembly may include a means for moving molten target material from the molten target material reservoir. Such means may include a pump. Such means may include a pressure vessel configured to control the pressure of a gas therein to exert a pressure on molten target material within the vessel. The vessel may be the molten target material reservoir.

[0024] The assembly may include valves configured to control the flow of molten target material through the assembly. Such valves may be freeze valves.

[0025] According to a third aspect of the present disclosure, there is provided a radiation source including a droplet generator according to the first aspect of the present disclosure or an assembly according to the second aspect of the present disclosure.

[0026] The radiation source is preferably an EUV radiation source, although it will be appreciated that other radiation sources may utilize the droplet generator or assembly described herein.

[0027] According to a fourth aspect of the present disclosure, there is provided a lithography apparatus including the droplet generator according to the first aspect of the present disclosure, an assembly according to the second aspect of the present disclosure, or a radiation source according to the third aspect of the present disclosure. Preferably, the lithography apparatus is an EUV lithography apparatus.

[0028] According to a fifth aspect of the present disclosure, there is provided a method of generating a stream of molten target material droplets, the method including providing a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction, said conduit being at least partially surrounded by a plurality of piezo elements, flowing a liquid target material through the conduit, and operating at least one of the plurality of piezo elements in shear mode such that shear motion of the piezo elements is in the molten target material direction to thereby generate a stream of molten target material droplets.

[0029] As described in respect of the first aspect of the present disclosure, by operating the piezo elements in shear mode such that the shear motion of the piezo elements is in the same direction as the molten target material direction, it is possible to perturb the velocity of the molten target material flowing through the conduit and cause it to separate into droplets. It is also possible to apply a larger potential difference before the polarization is flipped and so greater sensitivity can be provided.

[0030] The method may include operating the plurality of piezo elements at a frequency of from around 20 kHz to around 20 MHz.

[0031] According to a sixth aspect of the present disclosure, there is provided the use of a droplet generator according to a first aspect, as assembly according to the second aspect, a radiation source according to the third aspect, a lithography apparatus according to the fourth aspect or a method according to the fifth aspect of the present disclosure in a lithography method or apparatus.

[0032] The features described in respect of any of the aspects may be combined with the features described in respect of any of the other aspects of the present invention.

[0033] The present invention will now be described with reference to an EUV lithography apparatus. However, it will be appreciated that the present invention is not limited to EUV lithography and may be suitable for other types of lithography.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source;
Figure 2 depicts the d33, d31, and d15 modes of a piezoelectric element;
Figures 3 depicts a prior art configuration in which the piezoelectric element is configured to be excited in the d33 and d31 modes;
Figure 4 depicts an embodiment of the present disclosure including a pre-load tube;
Figure 5 depicts an embodiment of the present disclosure including a plurality of piezo elements with alternating potential differences applied and poling along the axis of the conduit;
Figure 6 depicts one configuration of electrodes according to the present disclosure;
Figure 7 depicts the shape which would be formed if the piezo elements were free;
Figures 8a and 8b depict two embodiments according to the present disclosure; and
Figure 9 depicts an embodiment in which the piezo element partially surrounds the conduit.

DETAILED DESCRIPTION

[0035] Figure 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS and a substrate table WT configured to support a substrate W. A pellicle 15 may be provided to protect the patterning device MA from contamination.

[0036] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a facetted field mirror device 10 and a facetted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B with a desired cross-sectional shape and a desired intensity distribution. The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

[0037] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13,14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13,14 in Figure 1, the projection system PS may include a different number of mirrors (e.g., six or eight mirrors).

[0038] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a pattern previously formed on the substrate W.

[0039] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or in the projection system PS.

[0040] The radiation source SO shown in Figure 1 is, for example, of a type which may be referred to as a laser produced plasma (LPP) source. A laser system 1, which may, for example, include a CO_2 laser, is arranged to deposit energy via a laser beam 2 into a fuel, such as tin (Sn) which is provided from, e.g., a fuel emitter 3. Fuel emitter 3 may be connected to a droplet generator apparatus according to the present disclosure. Although tin is referred to in the following description, any suitable fuel may be used. The fuel is in liquid form, and may, for example, be a metal or alloy. The fuel emitter 3 may comprise a nozzle configured to direct tin, e.g. in the form of droplets, along a trajectory towards a plasma formation region 4. The laser beam 2 is incident upon the tin at the plasma formation region 4. The deposition of laser energy into the tin creates a tin plasma 7 at the plasma formation region 4. Radiation, including EUV radiation, is emitted from the plasma 7 during de-excitation and recombination of electrons with ions of the plasma.

[0041] The EUV radiation from the plasma is collected and focused by a collector 5. Collector 5 comprises, for example, a near-normal incidence radiation collector 5 (sometimes referred to more generally as a normal-incidence radiation collector). The collector 5 may have a multilayer mirror structure which is arranged to reflect EUV radiation (e.g., EUV radiation having a desired wavelength such as 13.5 nm). The collector 5 may have an ellipsoidal configuration, having two focal points. A first one of the focal points may be at the plasma formation region 4, and a second one of the focal points may be at an intermediate focus 6, as discussed below.

[0042] The laser system 1 may be spatially separated from the radiation source SO. Where this is the case, the laser beam 2 may be passed from the laser system 1 to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser system 1, the radiation source SO and the beam delivery system may together be considered to be a radiation system.

[0043] Radiation that is reflected by the collector 5 forms the EUV radiation beam B. The EUV radiation beam B is focused at intermediate focus 6 to form an image at the intermediate focus 6 of the plasma present at the plasma formation region 4. The image at the intermediate focus 6 acts as a virtual radiation source for the illumination system IL. The radiation source SO is arranged such that the intermediate focus 6 is located at or near to an opening 8 in an enclosing structure 9 of the radiation source SO.

[0044] Figure 2 depicts three modes of a piezoelectric material. In the d33 mode, the polarization (as shown by the three arrows within the piezoelectric material 17) and the direction of the electric field E_3 are in the same direction. Similarly, in the d31 mode, the polarization (as shown by the three arrows within the piezoelectric material 17) and the direction of the electric field E_3 are in the same direction. The d33 and d31 modes cause deformation in the thickness 16 and length 16' directions of the piezo material. In the d15 mode, the polarization (as shown by the three arrows within the piezoelectric material 17) and the electric field E_1 are perpendicular, which results in deformation in the shear 16" direction.

[0045] Figure 3 depicts an embodiment of an existing configuration in which the piezoelectric material 17 is configured to be excited in the d33 and d31 modes. The dashed lines depict the exaggerated movement of the piezoelectric material 17 and the double headed arrows indicate the direction of movement of the piezoelectric material 17. The piezoelectric material 17 at least partially surrounds a conduit 18 through which molten target material flows when in use and the d33 and d31 modes deform the conduit 18, which causes the stream of molten target material to form droplets as it leaves the conduit 18.

[0046] Figure 4 depicts an embodiment according to the present disclosure in which the piezo elements 17, 17' are configured to operate in shear mode such that the direction of the shear movement is in the same direction as the flow F of molten target material though the conduit 18. The piezoelectric elements 17, 17' are shown in exaggerated shear deformation. The piezoelectric elements 17, 17' are shown as segmented and are alternately poled such that the shear deformation occurs in opposing directions along the axis of flow F of the molten target material. In this embodiment, the piezo elements 17, 17' are cylinders surrounding the conduit 18. In this embodiment, a pre-load tube 19 is provided surrounding the piezo elements 17, 17' and is configured to retain the piezo elements 17, 17' in the desired position such that when excited, the deformation of the piezo elements 17, 17' caused deformation of the conduit 18. Although two piezo elements 17, 17' are depicted, it will be appreciated that the present disclosure is not limited to any particular number of piezo elements.

[0047] Figure 5 depicts an embodiment of the present disclosure in which a plurality of piezo elements 17 are provided surrounding a conduit 18. The poling P is along the length of the conduit 18, with the potential difference applied to each piezo element 17 being alternated between positive and negative. The conduit 18 may held at 0V. A pre-load tube (not shown) may be provided.

[0048] Figure 6 depicts one possible configuration of electrodes, with a ground electrode 20 (shown as a dashed line) being provided around the central conduit 18 and secondary electrodes 21 configured to provided alternating positive and negative voltages along the conduit 18. The direction of the electric fields is shown by the black arrows between the ground electrode 20 and the secondary electrodes 21.

[0049] Figure 7 is a schematic representation of the configuration which would be adopted by free piezo elements 17 should then not be attached to the conduit 18 and/or constrained by a pre-load tube (not shown). As will be appreciated, by affixing the piezo elements 17 to the conduit 18, such as by gluing, and/or by constraining the piezo elements 17, such as by the provision of a preload tube at least partially surrounding the piezo elements 17, the shear deformation of the piezo elements 17 is able to deform the conduit 18, and consequently perturb the velocity of molten target material flowing through the conduit.

[0050] Figure 8a and Figure 8b depict two embodiments of the present disclosure. In Figure 8a, a conduit 18 is surrounded by piezo elements 17. The piezo elements 17 are polarized (as shown by the black arrows within the piezo elements) along the direction of the conduit 18, with some being parallel and others being antiparallel. In Figure 8a, there is a gap between adjacent piezo elements 17 and in Figure 8b, there is no gap between adjacent piezo elements 17. Within the conduit 18 is a molten target material 22. It will be appreciated that a pre-load tube (not shown) may be provided at least partially surrounding the piezo elements 17.

[0051] In use, a molten target material 22, such as molten tin, is passed through conduit 18. The piezo elements 17 which surround the conduit 18 and are poled in the direction of the molten target material flow are exposed to an electric field at right angles to the poling such that the piezo elements 17 deform in shear mode in the same direction as the molten target material flow. The effect of the piezo element 17 operating in shear mode is that the velocity of the molten target material is perturbed such that the flow forms droplets upon leaving the conduit 18.

[0052] Figure 9 depicts an embodiment in which a piezo element 17 partially surrounds the conduit 18. The piezo element 17 in this embodiment is in a c-shaped configuration with a circumferential gap. Although one piezo element 17 is shown, it will be appreciated that there may be any number of piezo elements 17.

[0053] The present invention provides for systems and methods for producing a stream of droplets of a molten target material. By operating piezo elements in shear mode in the same direction as the flow of molten target material, at the higher frequencies which next generation lithography machines will operate, it is possible to achieve higher sensitivity. Sensitivity is a measure of how much energy can be transferred to the molten target material for a given potential difference. As such, having a higher sensitivity at higher frequencies means that the transfer of energy from the piezo elements is more efficient. In addition, by arranging the poling and application of potential difference as described herein, it is possible to apply positive and/or negative voltages to the piezo elements without the field flipping and so greater potential differences can be provided which result in more energy transfer to the molten target material with the associated improvement in performance.

[0054] Other aspects of the invention are set out in the following numbered clauses.

1. A droplet generator comprising:

    a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction;
    a plurality of piezo elements at least partially surrounding the conduit,
    characterized in that at least one of the piezo elements in configured to operate in shear mode such that shear motion of the at least one piezo element is in the molten target material direction.

2. The droplet generator according to clause 1, wherein the conduit is a capillary, optionally a glass capillary.
3. The droplet generator according to clause 1 or clause 2, wherein the droplet generator further includes a controller configured to control voltage applied to the piezo elements.
4. The droplet generator according to any preceding clause, wherein at least one of the piezo elements includes segmented electrodes.
5. The droplet generator according to clause 4, wherein the segmented electrodes are interdigitated.
6. The droplet generator according to clause 4, wherein at least one of the segmented electrodes extends from an internal face of a piezo element to an external face of a piezo element.
7. The droplet generator according to any preceding clause, wherein the droplet generator further includes a pre-load tube at least partially surrounding the plurality of piezo elements.
8. The droplet generator according to any preceding clause, wherein the droplet generator is configured to provide a positive or negative potential difference to the plurality of piezo elements.
9. The droplet generator according to any preceding clause, wherein a gap is provided between adjacent piezo elements, preferably in a direction of a longitudinal axis of the conduit.
10. The droplet generator according to any preceding clause, wherein the piezo elements are arranged such that poling is alternated along the conduit.
11. The droplet generator according to any preceding clause, wherein the molten target material is a liquid metal, preferably tin.
12. An assembly for a lithography apparatus including the droplet generator according to any preceding clause.
13. A radiation source including a droplet generator or assembly according to any of clauses 11 or 12.

14. A lithography apparatus including the droplet generator, assembly, or radiation source according to any preceding clause.

15. A method of generating a stream of molten target material droplets, the method including providing a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction, said conduit being at least partially surrounded by a plurality of piezo elements, flowing a liquid target material through the conduit, and operating at least one of the plurality of piezo elements in shear mode such that shear motion of the piezo elements is in the molten target material direction to thereby generate a stream of molten target material droplets.

16. The method according to clause 15, wherein the method further including operating the plurality of piezo elements at a frequency of around 20 kHz to around 20 MHz.

17. The use of a droplet generator according to any of clauses 1 to 11, an assembly according to clause 12, a radiation source according to clause 13, a lithography apparatus according to clause 14, or a method according to clause 15 or 16 in a lithography method or apparatus.

[0055] 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 droplet generator comprising:

a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction;
a plurality of piezo elements at least partially surrounding the conduit,
characterized in that at least one of the piezo elements in configured to operate in shear mode such that shear motion of the at least one piezo element is in the molten target material direction.

2. The droplet generator according to claim 1, wherein the conduit is a capillary, optionally a glass capillary.

3. The droplet generator according to claim 1 or claim 2, wherein the droplet generator further includes a controller configured to control voltage applied to the piezo elements.

4. The droplet generator according to any preceding claim, wherein at least one of the piezo elements includes segmented electrodes.

5. The droplet generator according to claim 4, wherein the segmented electrodes are interdigitated.

6. The droplet generator according to claim 4, wherein at least one of the segmented electrodes extends from an internal face of a piezo element to an external face of a piezo element.

7. The droplet generator according to any preceding claim, wherein the droplet generator further includes a pre-load tube at least partially surrounding the plurality of piezo elements.

8. The droplet generator according to any preceding claim, wherein the droplet generator is configured to provide a positive or negative potential difference to the plurality of piezo elements.

9. The droplet generator according to any preceding claim, wherein a gap is provided between adjacent piezo elements, preferably in a direction of a longitudinal axis of the conduit.

10. The droplet generator according to any preceding claim, wherein the piezo elements are arranged such that poling is alternated along the conduit.

11. The droplet generator according to any preceding claim, wherein the molten target material is a liquid metal, preferably tin.

12. An assembly for a lithography apparatus including the droplet generator according to any preceding claim.

13. A radiation source including a droplet generator or assembly according to any of claims 11 or 12.

14. A lithography apparatus including the droplet generator, assembly, or radiation source according to any preceding claim.

15. A method of generating a stream of molten target material droplets, the method including providing a conduit comprising an orifice configured to fluidly couple to a reservoir and to emit molten target material in a molten target material direction, said conduit being at least partially surrounded by a plurality of piezo elements, flowing a liquid target material through the conduit, and operating at least one of the plurality of piezo elements in shear mode such that shear motion of the piezo elements is in the molten target material direction to thereby generate a stream of molten target material droplets.

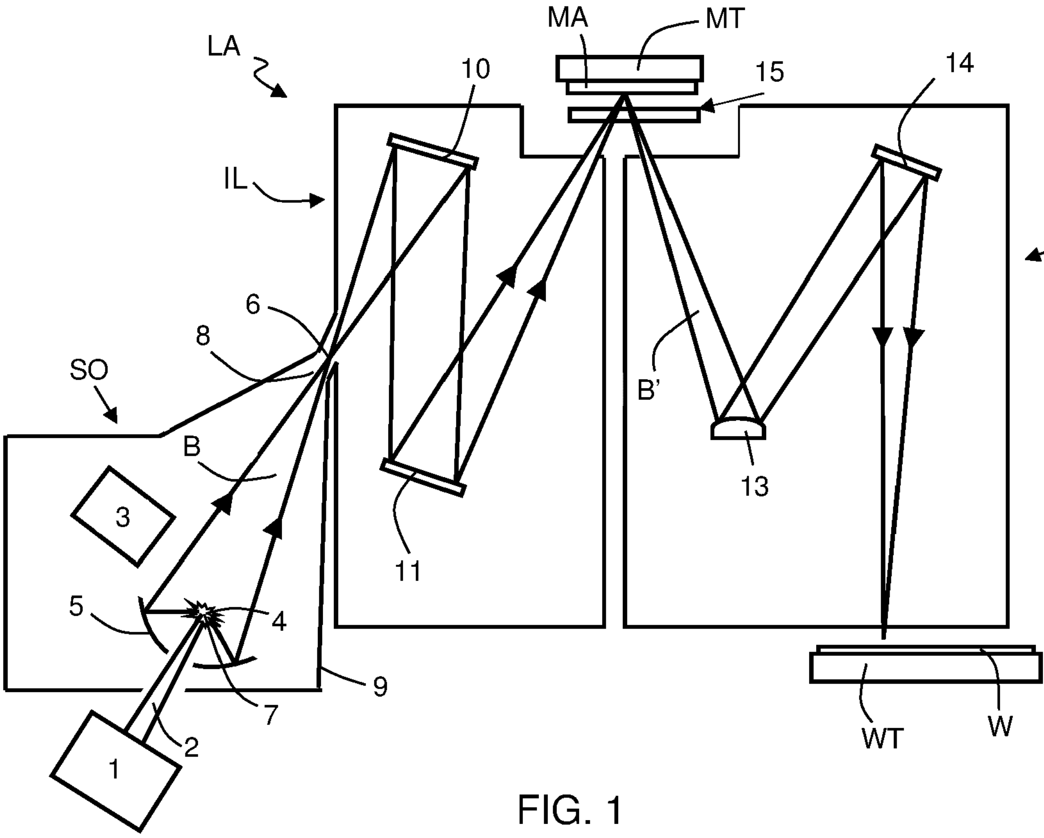

FIG. 1

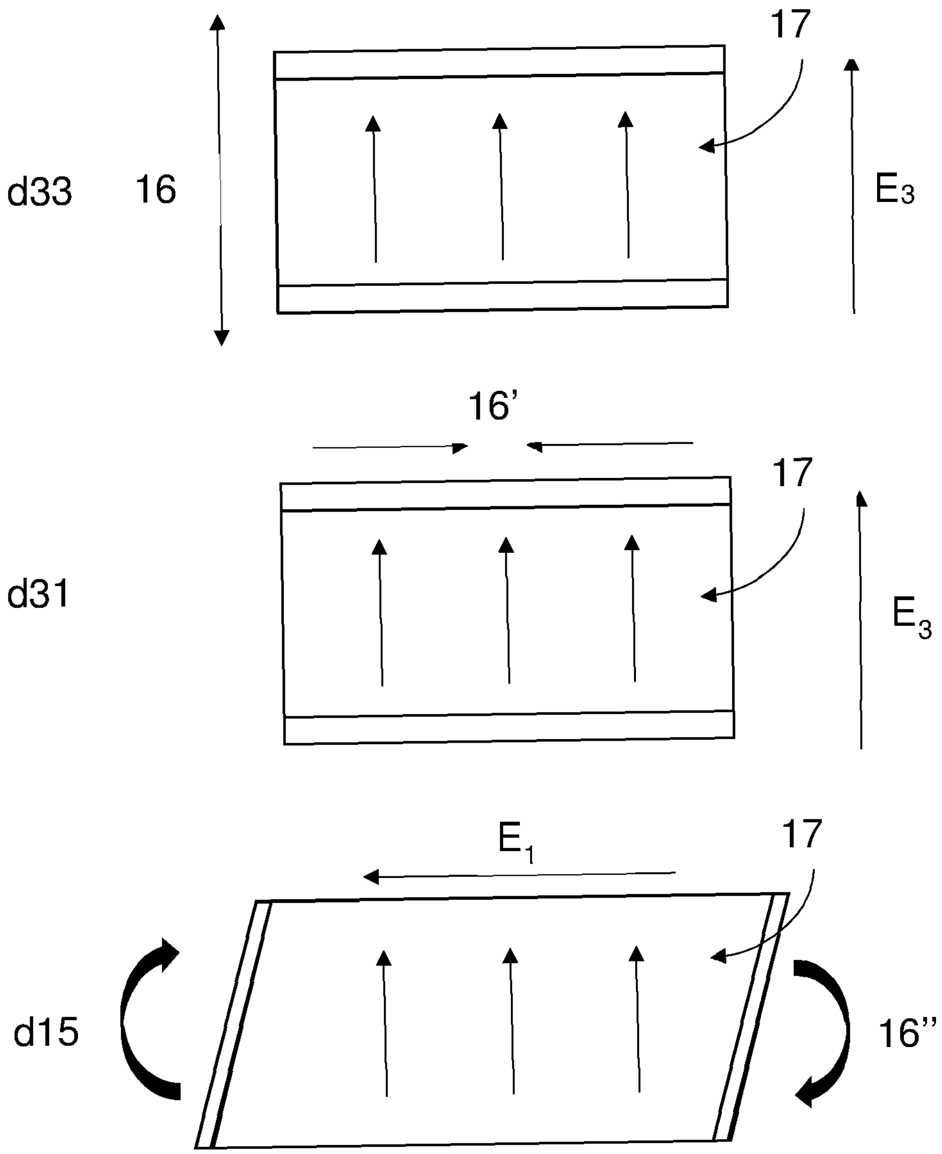

FIG. 2

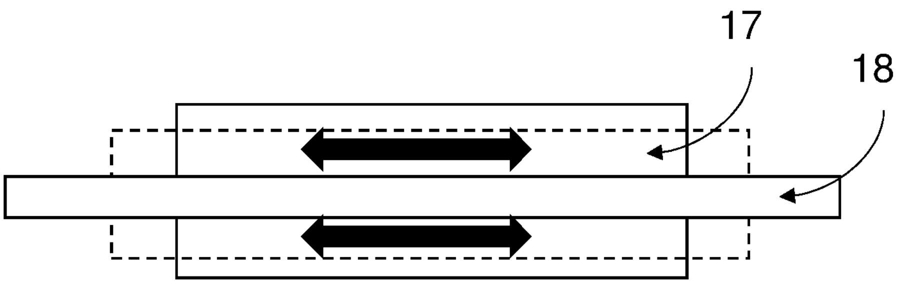

FIG. 3

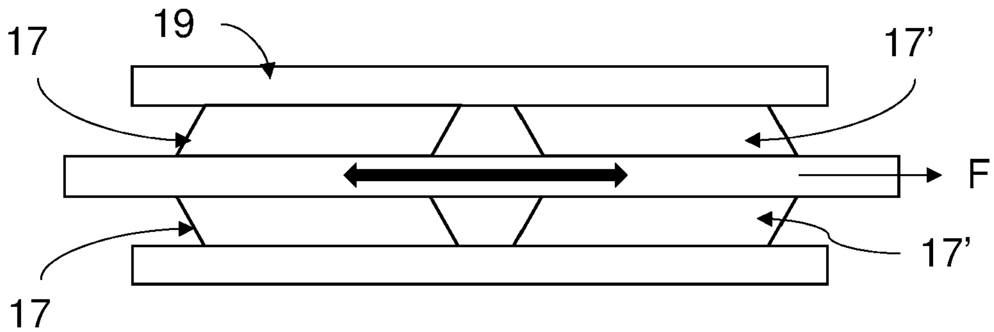

FIG. 4

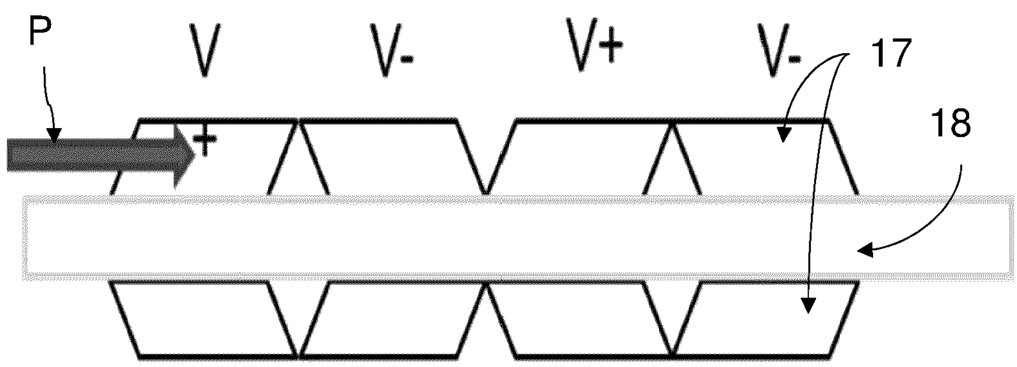

FIG. 5

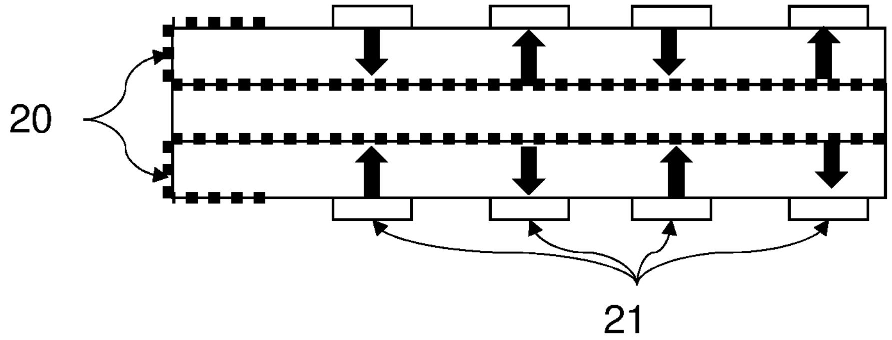

FIG. 6

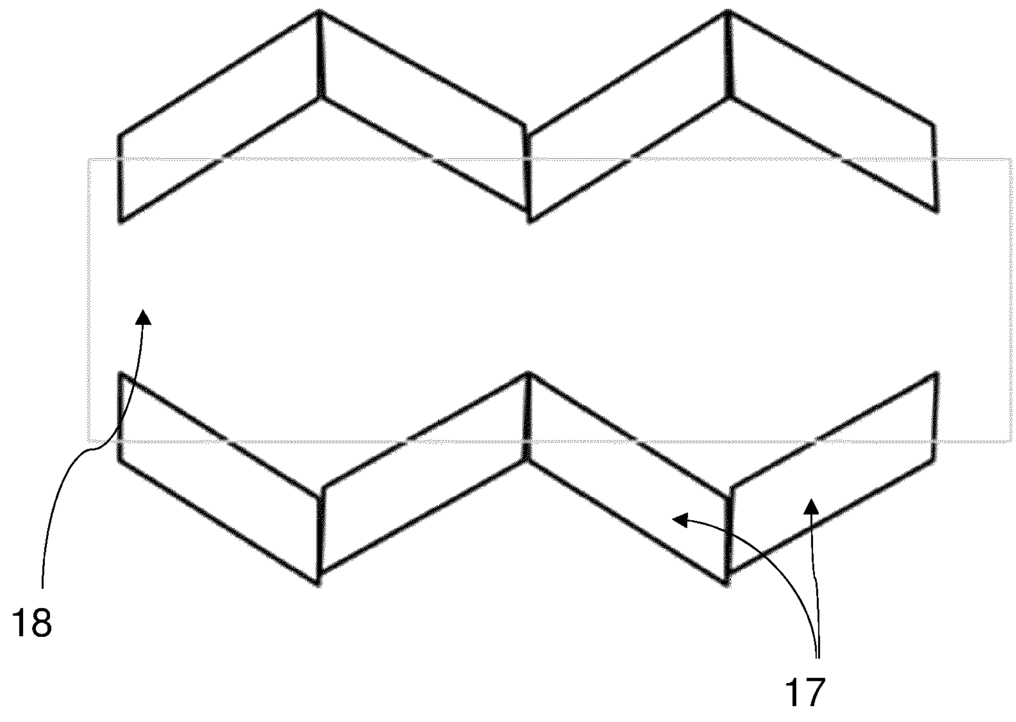

FIG. 7

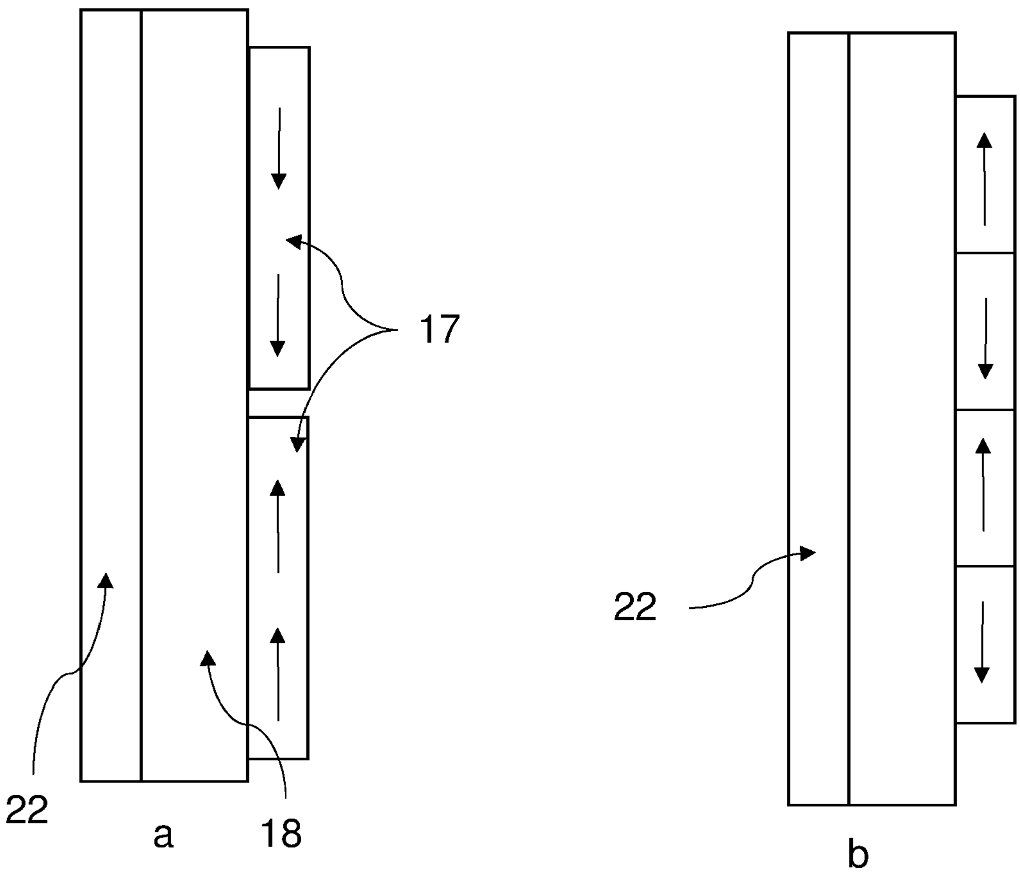

FIG. 8

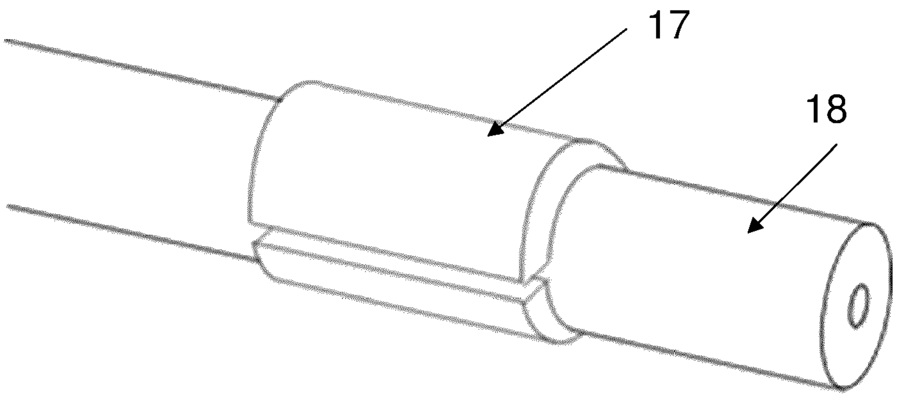

FIG. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 23 17 4083

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WILLIAMS G ET AL: "Non-planar interconnect", CIRCUIT WORLD, EMERALD GROUP PUBLISHING LIMITED, GB, vol. 31, no. 2, 1 January 2005 (2005-01-01), pages 10-14, XP007901380, ISSN: 0305-6120, DOI: 10.1108/03056120510571798 * Patterning of an ink-jet print head * -----	1-4,6,8, 10,15	INV. H05G2/00
X	US 4 825 227 A (FISCHBECK KENNETH H [US] ET AL) 25 April 1989 (1989-04-25) * figures 1-3 * * column 2, line 54 - column 4, line 29 * -----	1,3-6,8, 15	
X	US 2020/079696 A1 (WATSON MICHAEL [GB] ET AL) 12 March 2020 (2020-03-12) * paragraphs [0072] - [0078]; figure 1 * -----	1-4,8,15	
A	US 2015/206738 A1 (RASTEGAR ABBAS [US]) 23 July 2015 (2015-07-23) * figures 12,13A,14,15 * * paragraphs [0009], [0070], [0084] - [0086] * -----	5	TECHNICAL FIELDS SEARCHED (IPC) B41J

~~The present search report has been drawn up for all claims~~

3

Place of search	Date of completion of the search	Examiner
Munich	17 November 2023	Giovanardi, Chiara

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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Application Number
EP 23 17 4083

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-6, 8, 10, 15

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 23 17 4083

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6, 8, 10, 15

A droplet generator and method of generating the droplets comprising: a conduit comprising an orifice configured to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, wherein at least one of them is configured to operate in shear mode such that its shear motion is in the molten target material direction.
It adds that at least one of the piezo elements includes segmented electrodes.

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2. claim: 7

A droplet generator and method of generating the droplets comprising: a conduit comprising an orifice configured to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, wherein at least one of them is configured to operate in shear mode such that its shear motion is in the molten target material direction.
It adds that the droplet generator further includes a pre-load tube at least partially surrounding the plurality of piezo elements.

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3. claim: 9

A droplet generator and method of generating the droplets comprising: a conduit comprising an orifice configured to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, wherein at least one of them is configured to operate in shear mode such that its shear motion is in the molten target material direction.
It adds that a gap is provided between adjacent piezo elements.

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4. claims: 11, 13

A droplet generator and method of generating the droplets comprising: a conduit comprising an orifice configured to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, wherein at least one of them is configured to operate in shear mode such that its shear motion is in the molten target material direction.
It adds that the molten target material is a liquid metal.

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LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 23 17 4083

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

5. claims: 12, 14

A droplet generator and method of generating the droplets comprising: a conduit comprising an orifice configured to emit molten target material in a molten target material direction; a plurality of piezo elements at least partially surrounding the conduit, wherein at least one of them is configured to operate in shear mode such that its shear motion is in the molten target material direction.
It adds a lithography apparatus.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 23 17 4083

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

17-11-2023

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			CA	1311964	C	29-12-1992
			DE	68916364	T2	19-01-1995
			EP	0364518	A1	25-04-1990
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			KR	900700858	A	17-08-1990
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82