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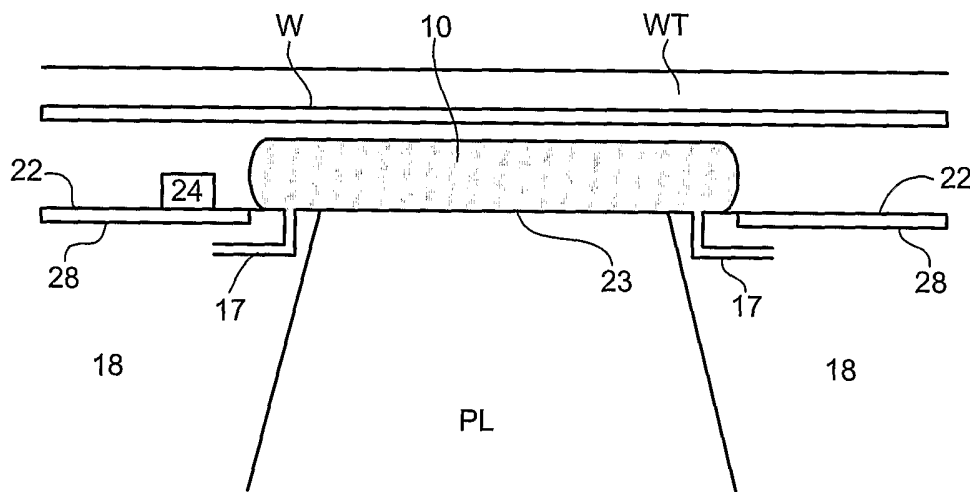
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(54) Title: LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD



(57) Abstract: Liquid is supplied to a space between the final element of the projection system and the substrate, but there is a space between the liquid and the substrate. An evanescent field is formed between the liquid and the substrate allowing some photons to expose the substrate. Due to the refractive index of the liquid, the resolution of the system is improved and liquid on the substrate is avoided.

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### **Lithographic Apparatus and Device Manufacturing Method**

The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- 5 - a substrate table for holding a substrate;
- a projection system for projecting the patterned beam onto a target portion of said substrate;
- a liquid supply system for supplying a liquid between a final element of said projection system and said substrate.

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The term "patterning means" as here employed should be broadly interpreted as referring to means 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. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

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- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- 20
- 25 - A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light

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as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array

5 employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing

10 pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT

15 patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

- A programmable LCD array. An example of such a construction is given in United

20 States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such

25 instances should be seen in the broader context of the patterning means as hereabove set forth.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (*e.g.* comprising one or more dies) on a substrate (silicon wafer) that has been coated

30 with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one

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at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative  
5 apparatus —commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor  $M$  (generally  $< 1$ ), the speed  $V$  at which the substrate table is scanned will be  
10 a factor  $M$  times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive  
15 material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to  
20 pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual  
25 devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

For the sake of simplicity, the projection system may hereinafter be referred to as the  
30 "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for

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example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

It has been proposed to immerse the substrate in a lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system.)

However, submersing the substrate or substrate and substrate table in a bath of liquid (see for example US 4,509,852, hereby incorporated in its entirety by reference) means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

One of the solutions proposed is for a liquid supply system to provide liquid on a localized area of the substrate and in between the final element of the projection system and the substrate (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a  $-X$  direction, liquid is supplied at the  $+X$  side of the element and taken up at the  $-X$  side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and

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numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element to form a liquid reservoir.

Another solution which has been proposed, as described in European patent application 5 03252955.4, is to provide the liquid supply system with a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. The seal member is substantially stationary relative to the projection system in the XY plane and a seal is formed between the seal member and the surface of the substrate. Preferably the seal is a contactless seal such as a gas seal.

10 However both these proposals can incur several difficulties. For example the effect of immersion liquid on resist chemistry is unknown and outgassing of the resist could cause bubbles in the immersion liquid. Bubbles in the immersion liquid would alter the course of the light and thus affect the uniformity of the exposure. Furthermore, even with protective measures, the problem of mechanical disturbances due to coupling between the projection apparatus and the 15 substrate via the immersion liquid remains significant.

An alternative method to improve the resolution of lithographic apparatus, as described by L. P. Ghislain et al in Near-Field Photolithography with Solid Immersion Lens, App. Phys Lett 74, 501-503 (1999), is to provide a solid immersion lens with a high refractive index between the projection system and the substrate. The projection beam is focused on the solid immersion lens 20 and the radiation propagates to the resist through a very thin air (or other gas) gap using an evanescent field (near-field operation mode). The distance between the solid lens and the substrate is made sufficiently small (i.e. less than the wavelength of the radiation) that some photons are transmitted across the gap and the substrate is exposed. This proposal obviously relies on a very small gap between the substrate and the solid lens and the chances of a crash 25 between the two are high.

It is an object of the present invention to provide an alternative method and apparatus with improved resolution. The alternative method and apparatus should alleviate some of the disadvantages of the presence of liquid or the presence of a solid lens.

30 This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, characterized in that said liquid supply system is

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arranged such that in use there is a space not occupied by liquid between said liquid and said substrate.

The problems resulting from the contact between the liquid and the substrate, such as the effect on resist chemistry and outgassing of the resist can be avoided. Similarly, even if a  
5 crash occurs between the liquid and the substrate the consequences will not be as serious as a crash between a solid lens and the substrate. The liquid may be dispersed in the system but the substrate will likely not be permanently damaged and the lithographic apparatus will likely not need major repair work. Arrangements to catch liquid dispersed in the event of a crash can easily be provided.

10 The liquid supply system can include elements to control the position, quantity, shape, flow rate or any other features of the liquid.

The distance between the liquid and the substrate is preferably smaller than the wavelength of the radiation and also preferably less than 100nm. The distance between the liquid and the substrate should be carefully monitored: if the distance is too great insufficient radiation  
15 will be transmitted to the substrate. The distance should also be as uniform as possible to prevent variation in the amount of light transmitted. Similarly, the depth of the liquid should be monitored as it affects the focal plane of the entire projection system. Both the distance between the liquid and the substrate and the depth of the liquid should be carefully regulated such that any variations can be compensated for.

20 To prevent erroneous and unquantified refraction of the radiation, the surface of the liquid closest to the substrate should be substantially parallel to the substrate.

To confine the water to form a liquid lens the liquid supply system comprises a hydrophobic surface. The hydrophobic surface should preferably be of a substantially annular shape to form the liquid lens in the center of the annulus. There is preferably also a radiation-  
25 transmissive hydrophilic surface for defining the shape of the liquid. The hydrophilic surface preferably fills the hole at the center of the annular hydrophobic surface. A metallic electrode can also be used to adjust the shape (including diameter) of the liquid.

For ease of use the lithographic apparatus is preferably arranged such that the substrate table is vertically above the projection system.

30 According to a further aspect of the invention there is provided a device manufacturing method comprising the steps of:

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- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
  - providing a projection beam of radiation using a radiation system;
  - using patterning means to endow the projection beam with a pattern in its cross-section;
  - 5 - providing a liquid between a final element of a projection system used in said step of projecting and said substrate;
  - projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,
- characterized in that said liquid forms a liquid lens and that, after traversing said liquid lens, said  
10 projection beam traverses a space before exposing said substrate.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the  
15 manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

20 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).

25

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 projection apparatus according to an embodiment of the invention;

30 Figure 2 depicts a liquid supply system according to an embodiment of the invention;

Figure 3 is an alternative view of the liquid supply system of Figure 2;



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Figure 4 depicts a detail of a lithographic projection apparatus according to an embodiment of the invention; and

Figure 5 depicts a detail of an alternative embodiment of a lithographic projection apparatus according to the invention.

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In the Figures, corresponding reference symbols indicate corresponding parts.

Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

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- a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* UV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (*e.g.* a refractive lens system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

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As here depicted, the apparatus is of a transmissive type (*e.g.* has a transmissive mask).

However, in general, it may also be of a reflective type, for example (*e.g.* with a reflective mask).

Alternatively, the apparatus may employ another kind of patterning means, such as a

25

programmable mirror array of a type as referred to above.

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The source LA (*e.g.* a laser-produced or discharge plasma source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a

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condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the y direction) with a speed  $v$ , so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed  $V = Mv$ , in which  $M$  is the magnification of the lens

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PL (typically,  $M = 1/4$  or  $1/5$ ). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

As shown in Figures 4 and 5 the substrate table WT is above the projection system PL (although as discussed hereafter it need not be). High precision liquid supply system 18 is provided to supply liquid via duct 17 to a space between the projection system PL and the substrate table WT. The liquid has a refractive index  $n$  and forms a liquid lens 10 or reservoir. The lens 10 is formed around the image field of the projection system PL so that liquid is confined to a space between the substrate surface and the final element of the projection system PL.

A band of a hydrophobic material 22 (e.g. a coating) is adhered to the liquid supply system 18 which confines liquid in the lens 10. Additionally, the surface of the projection system PL disposed towards the substrate surface comprises a radiation-transmissive hydrophilic material 23 (e.g. a coating) to ensure the lens adheres to the projection system. The specific choice of hydrophobic and hydrophilic materials is dependent on the liquid. For example, when using substantially water as the liquid, glass has been found to be a suitable hydrophilic material and Teflon a suitable hydrophobic material. Other factors such as the degree of roughness of the surface can also be used to improve the hydrophobic quality of a material.

A liquid sensor 24 senses the depth of the liquid lens 10 and the high precision liquid supply system 18 provides enough liquid to substantially fill the space between the projection lens and the substrate, but such that there is a gap between the substrate W and the liquid lens 10 of less than the wavelength of the projection radiation. Liquid sensor 24 forms part of a feedback system in which more liquid can be provided into the lens 10 by the high precision liquid supply system 18 when the depth is insufficient and liquid can be removed from the lens 10 by an outlet 14 (or one of the ducts 17 can be used as an outlet) when the depth is too great. The liquid sensor 24 works by sensing light from within the liquid lens 10 and using internal reflections from surfaces of the liquid lens to determine the depth of the lens. As the distance between the projection system PL and the substrate W can either be set or alternatively easily measured, the gap between the lens 10 and the substrate W can be calculated by simply subtracting the depth of the lens 10 from the total distance between the projection system PL and the substrate W. Alternatively these distances can be measured by measuring the capacitance between electrodes on, for example, the substrate table WT and the projection system PL.

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Radiation is thus projected through the liquid lens 10 and an evanescent field is formed between the substrate W and the surface of the liquid lens 10 disposed towards the substrate surface. The resolution of the system is therefore improved by a factor of  $n$ .

The lens 10 should preferably have a large flat surface to prevent erroneous refraction of the radiation. By charging (preferably metallic) electrodes 28 under the hydrophobic material the shape (form and size of the liquid lens can be adjusted appropriately. For example the lens 10 can be adjusted to have a large diameter to provide a large flat area at the center.

Alternatively or additionally to the hydrophobic material 22 and/or hydrophilic material 23 a gas seal 16 can be used to confine the liquid in the lens. As shown in Figure 5 the gas seal is formed by gas, e.g. air or synthetic air but preferably  $N_2$  or another inert gas, provided under pressure via inlet 15 to the gap between the high precision liquid supply system 18 and the substrate W and extracted via outlet 14. An overpressure on the gas inlet 15, vacuum level on the outlet 14 and geometry of the gap are arranged so that there is a high-velocity air flow inwards that confines the liquid.

If the lens 10 is sufficiently small, a lithographic apparatus with the projection system PL above the substrate table WT, as shown in Figure 1 can be used. Surface tension and adhesion forces compensate for the force of gravity and the lens 10 remains adhered to the projection system PL leaving a space between the lens 10 and the substrate W.

Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

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## CLAIMS:

1. A lithographic projection apparatus comprising:
  - a radiation system for providing a projection beam of radiation;
  - a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
  - 5 - a substrate table for holding a substrate;
  - a projection system for projecting the patterned beam onto a target portion of said substrate; and
  - a liquid supply system for supplying a liquid between a final element of said projection system and said substrate
- 10 characterized in that said liquid supply system is arranged such that in use there is a space not occupied by liquid between said liquid and said substrate.
  
2. An apparatus according to claim 1 wherein the distance between said liquid and said substrate is smaller than the wavelength of said radiation.
- 15
3. An apparatus according to claim 1 or claim 2 wherein said distance between said liquid and said substrate is less than 100nm.
  
4. An apparatus according to any one of the preceding claims wherein the majority of the surface of said liquid closest to said substrate is substantially parallel to said substrate.
- 20
5. An apparatus according to any one of the preceding claims wherein said liquid supply system comprises a hydrophobic surface for defining the shape of the liquid.
  
- 25 6. An apparatus according to any one of the preceding claims wherein said hydrophobic surface is of annular shape.
  
7. An apparatus according to any one of the preceding claims further comprising a radiation-transmissive hydrophilic surface for defining the shape of the liquid.

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8. An apparatus according to claim 7 characterized in that said radiation-transmissive hydrophilic surface is circular, filling the hole at the center of an annular hydrophobic surface.

5 9. An apparatus according to any one of the preceding claims wherein, in use, said substrate table is vertically above said projection system.

10. An apparatus according to any one of the preceding claims comprising an electrode for adjusting the shape of the liquid.

10

11. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- 15 - using patterning means to endow the projection beam with a pattern in its cross-section;
- providing a liquid between a final element of a projection system used in said step of projecting and said substrate;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

20 characterized in that said liquid forms a liquid lens and that, after traversing said liquid lens, said projection beam traverses a space before exposing said substrate.

Fig. 1

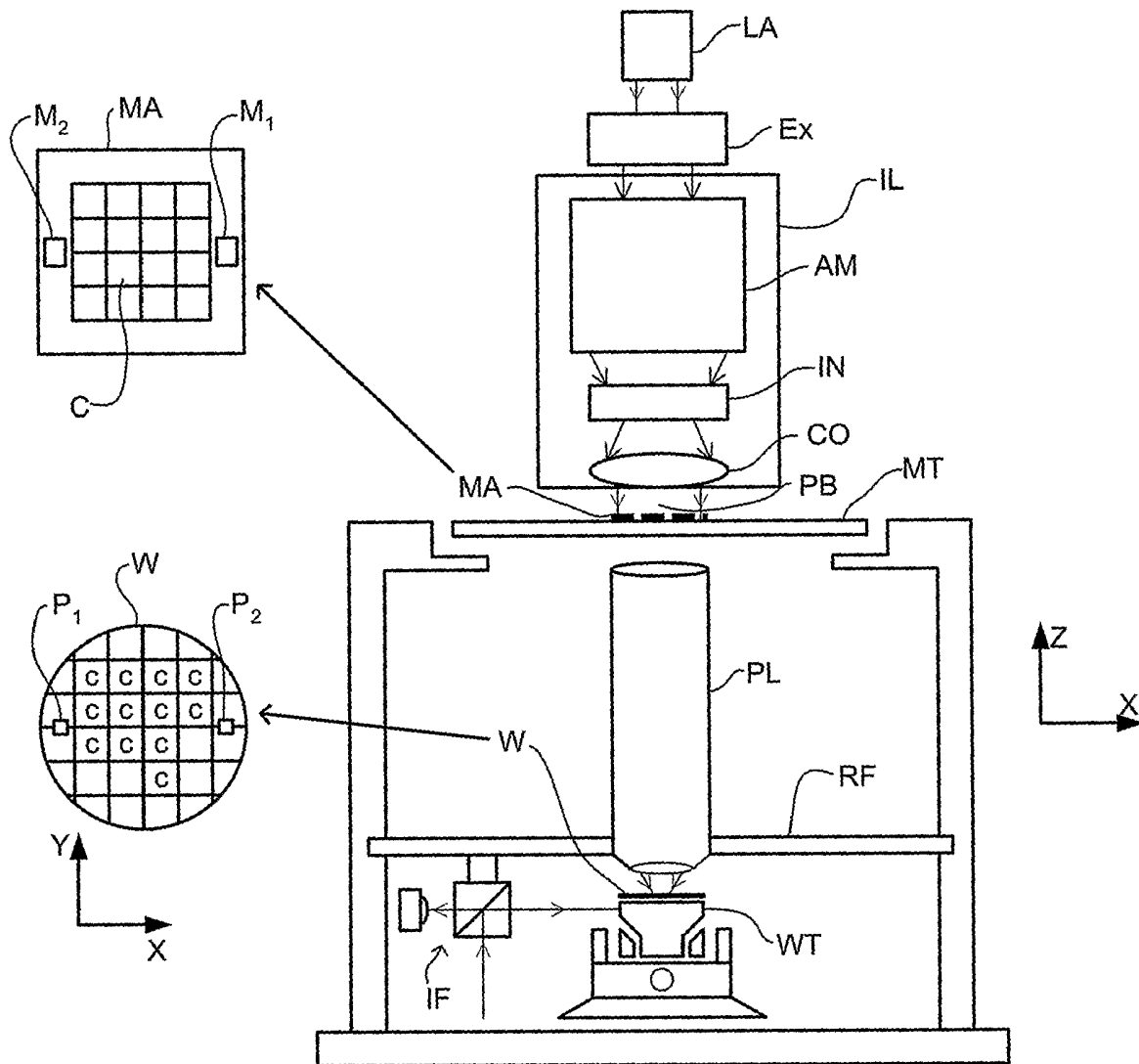


Fig. 2

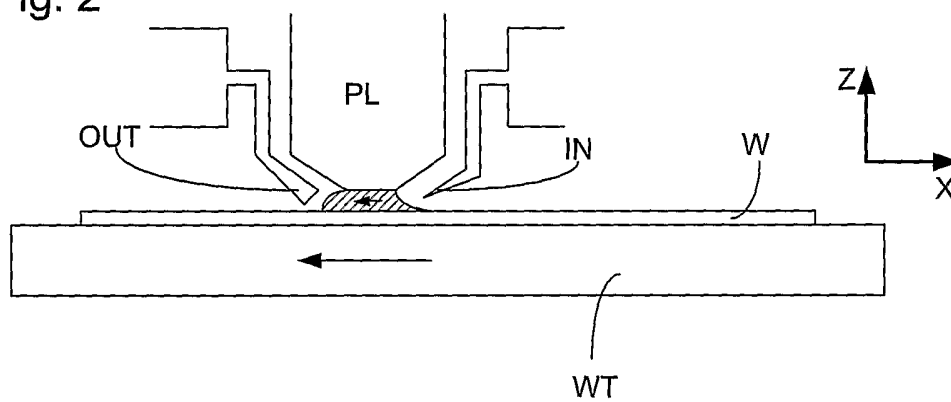


Fig. 3

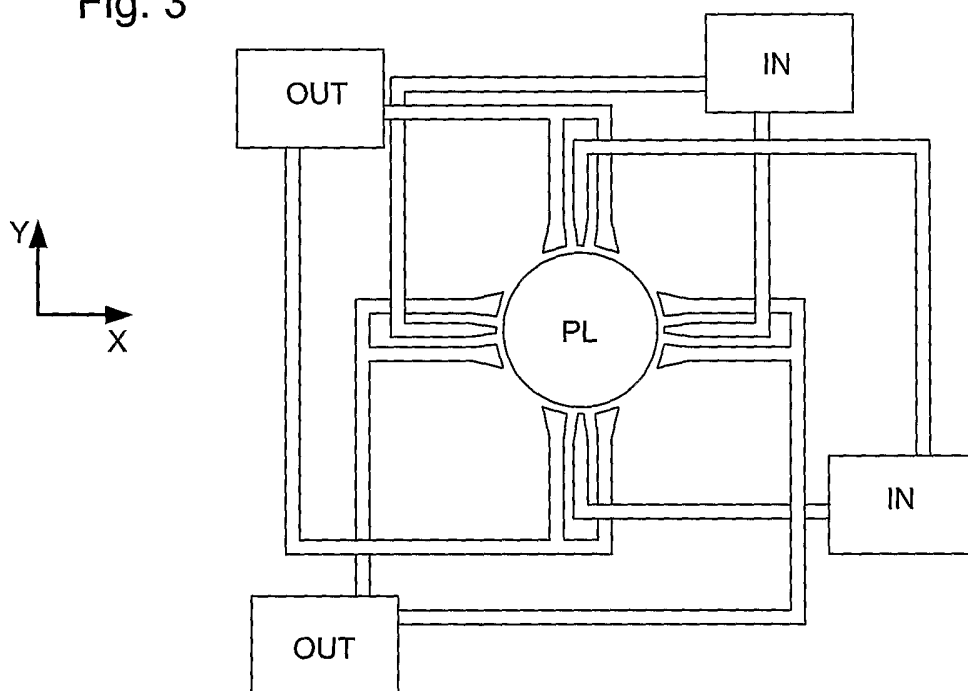




Fig. 4

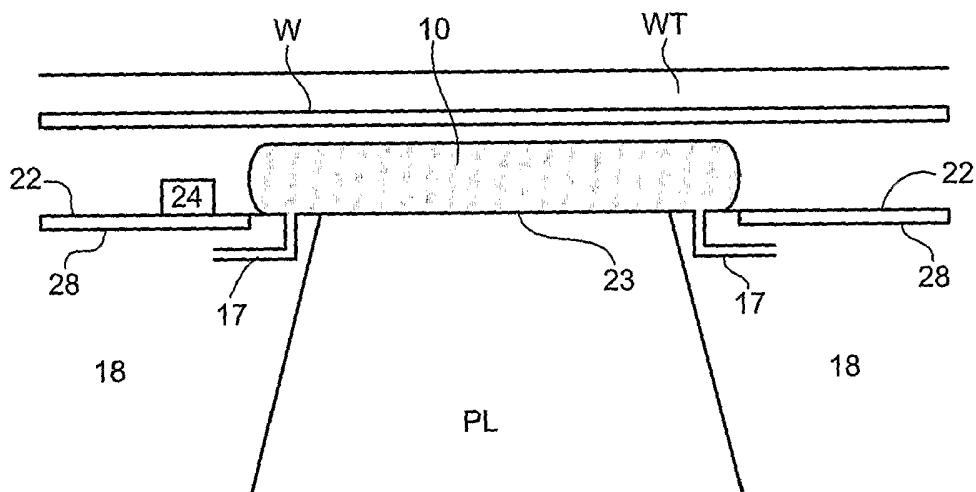


Fig. 5

