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(54) **DEVICE AND METHOD FOR LITHOGRAPHY**

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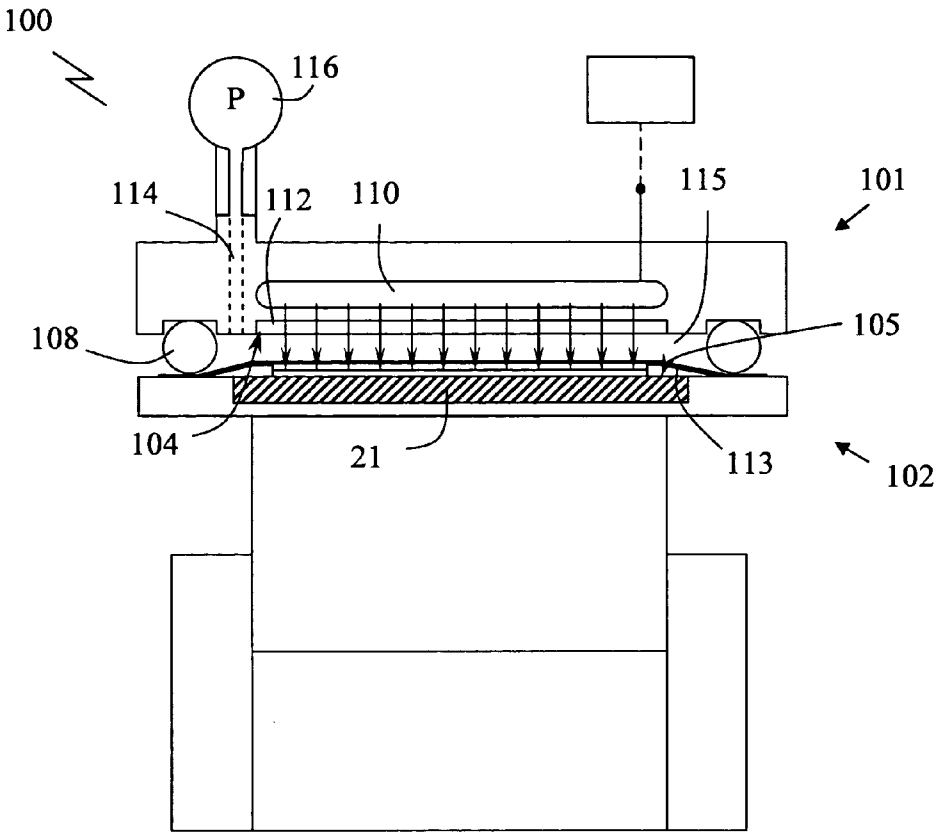
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(57) **ABSTRACT**

Apparatus and method for transferring a pattern from a template (**10**) having a structured surface to a substrate (**12**) carrying a surface layer of a radiation polymerisable fluid (**14**). The apparatus comprises a first main part (**101**) and a second main part (**102**) having opposing surfaces (**104;105**), means for adjusting a spacing (**115**) between said main parts, support means (**106**) for supporting said template and substrate in mutual parallel engagement in said spacing with said structured surface facing said surface layer, a radiation source (**110**) devised to emit radiation into said spacing. A cavity (**115**) has a first wall comprising a flexible membrane (**113**) devised to engage said template or substrate, and means (**114;116**) are provided for applying an adjustable overpressure to a medium present in said cavity, whereby an even distribution of force is obtained over the whole of the contact surface between the substrate and the template. The apparatus further includes a heater device having a surface facing said spacing, for heating either fluid layer (**14**).



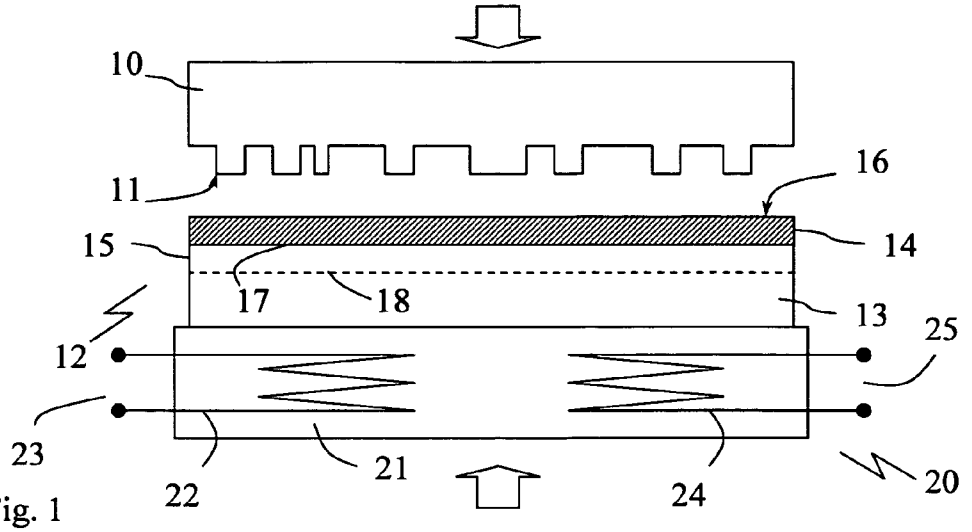


Fig. 1

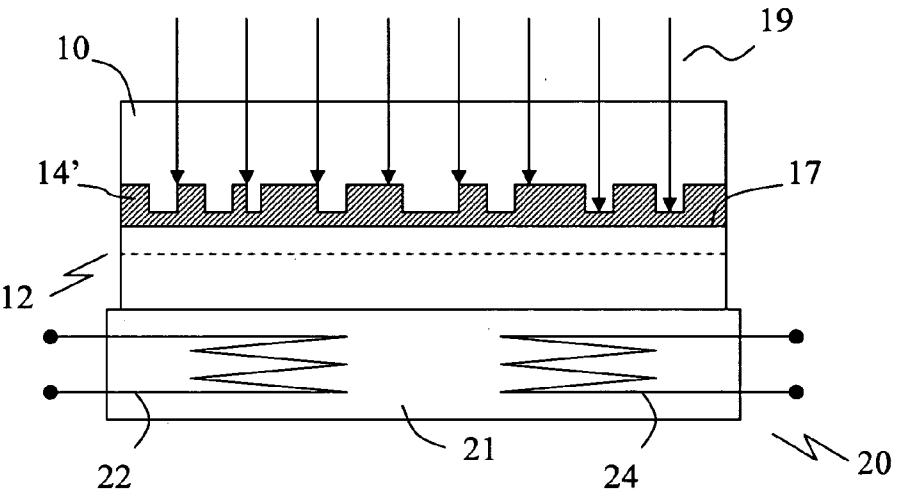


Fig. 2

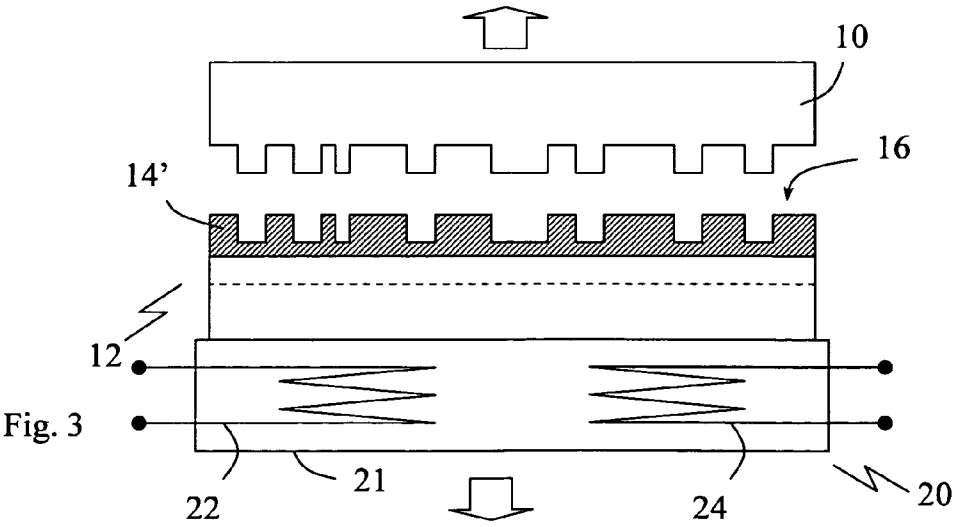


Fig. 3

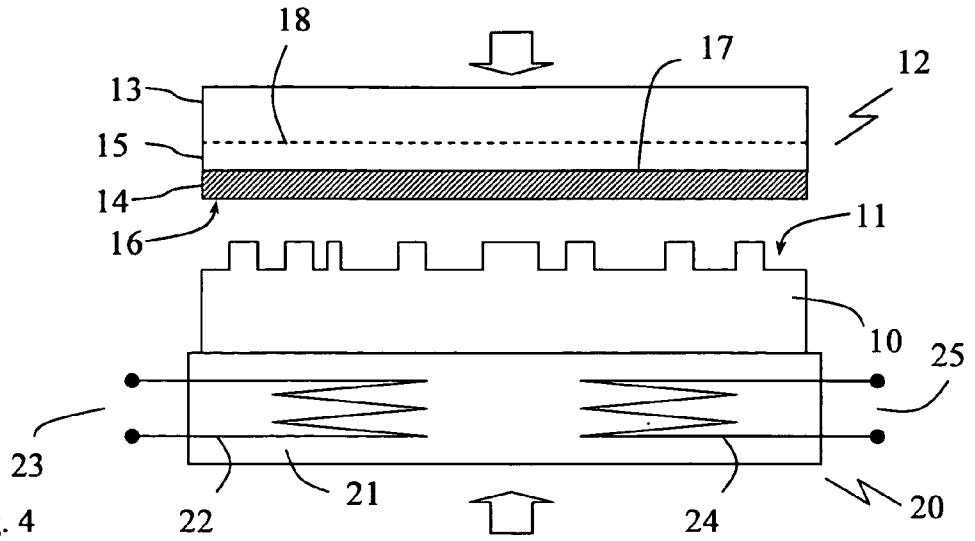


Fig. 4

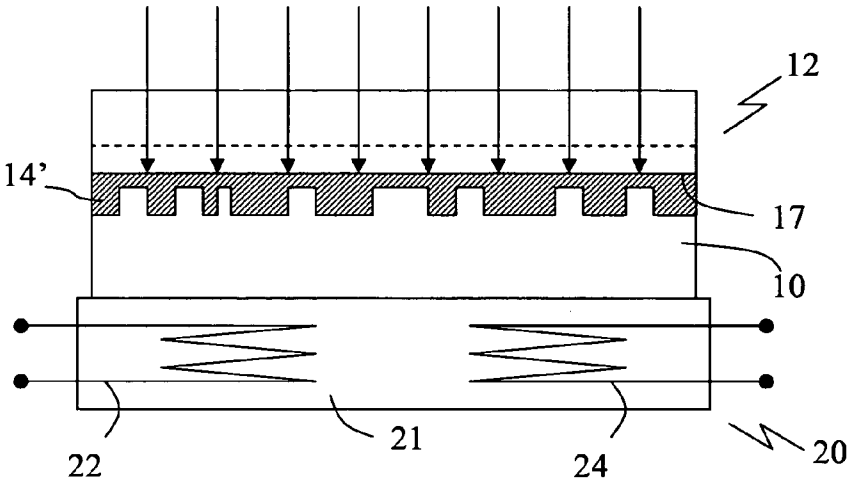


Fig. 5

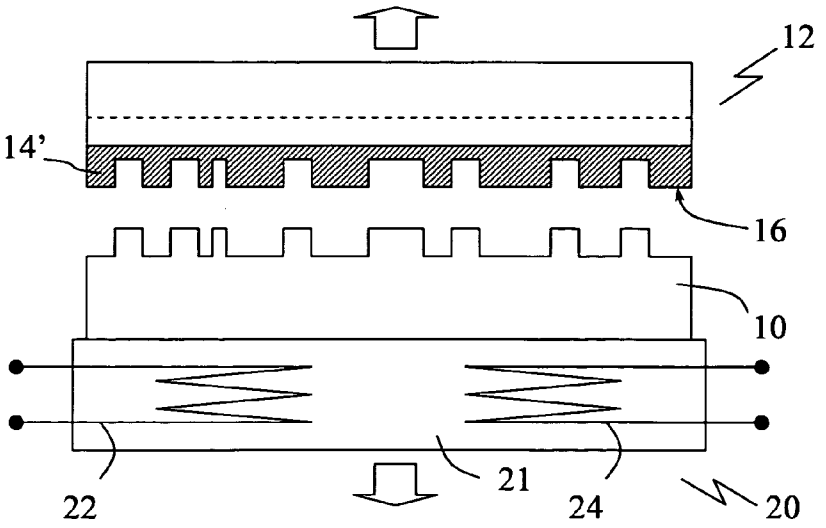


Fig. 6

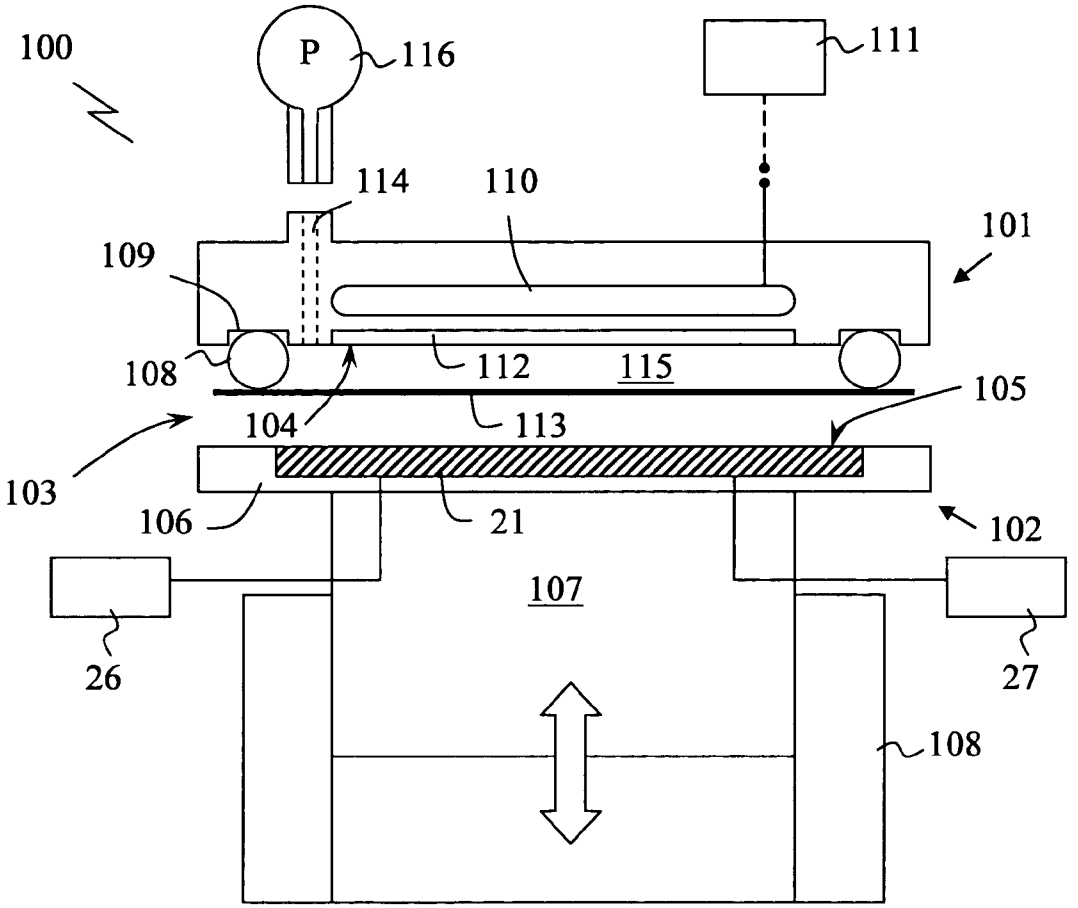

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Fig. 7

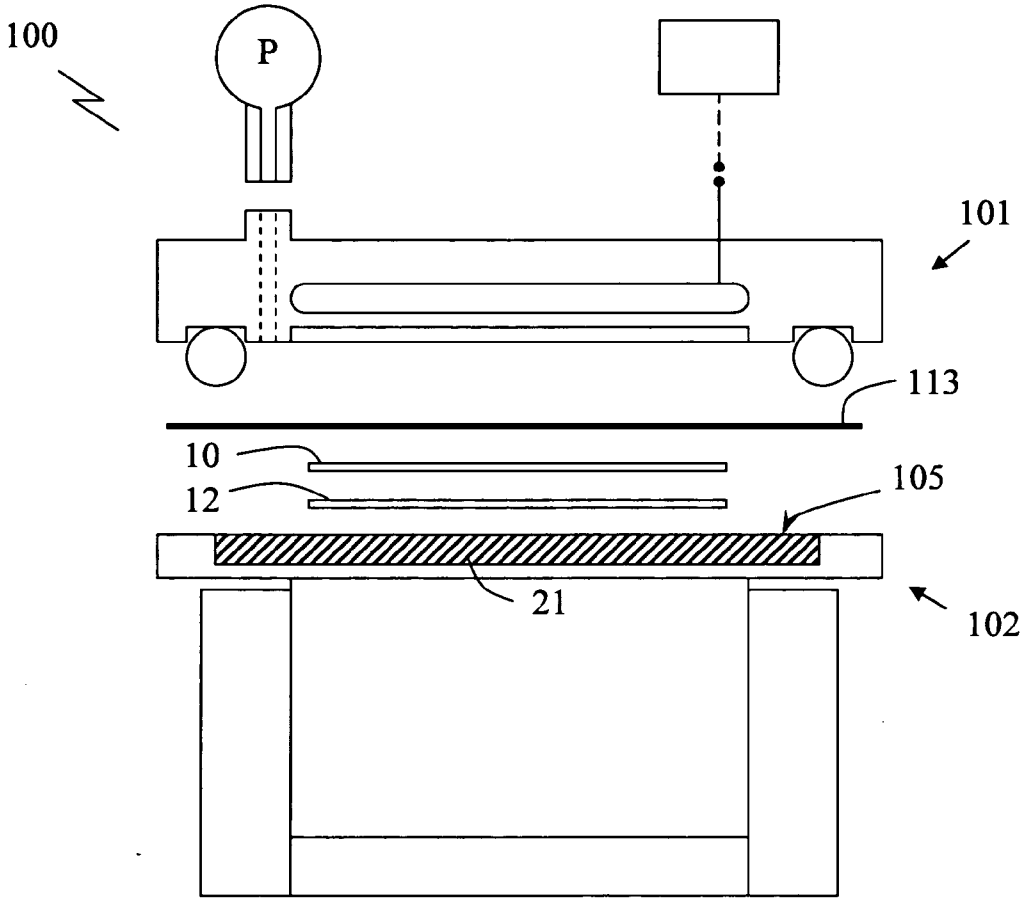


Fig. 8

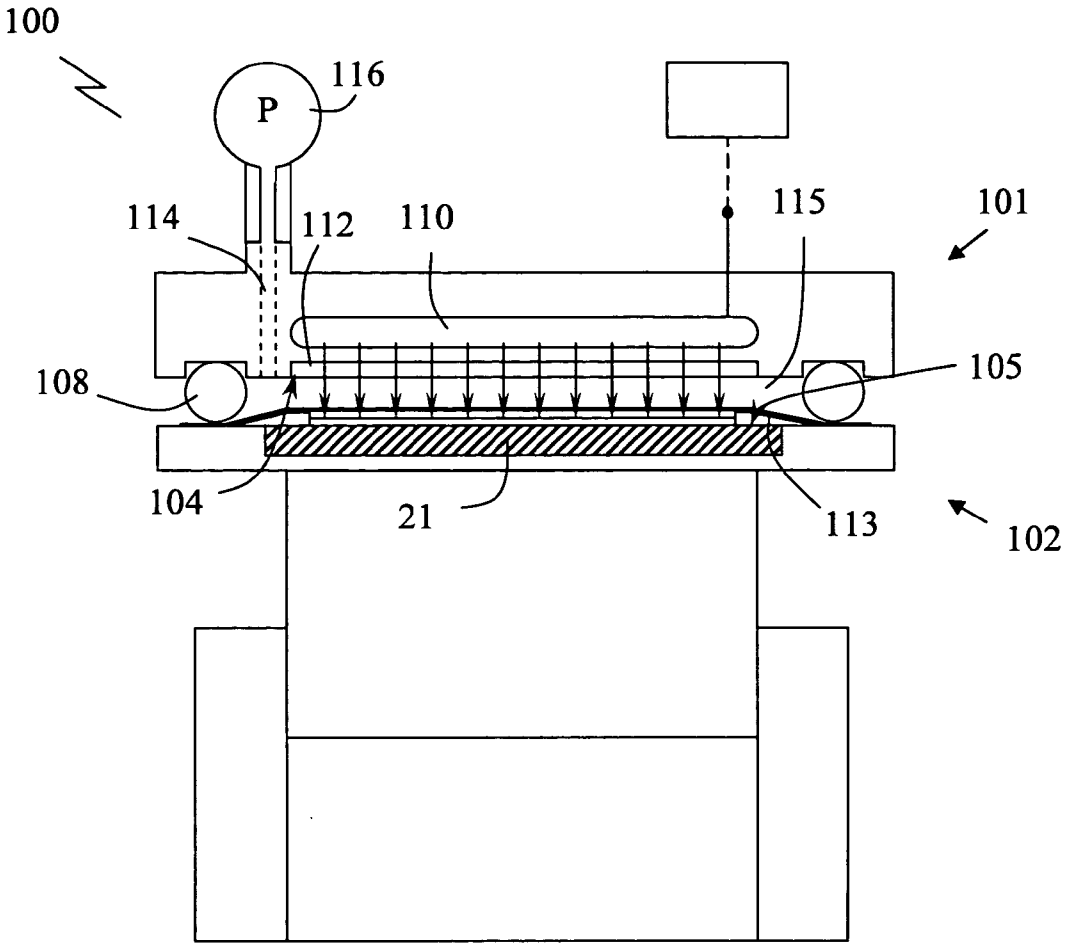


Fig. 9

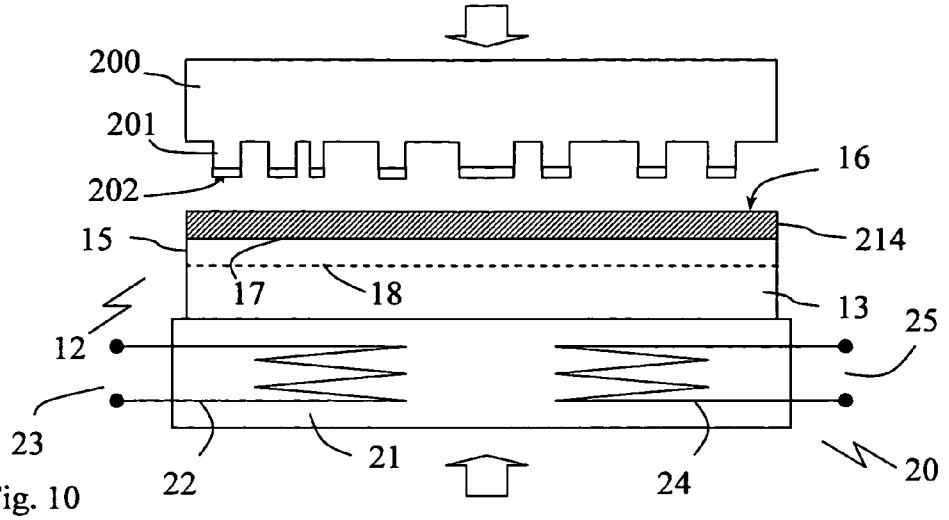


Fig. 10

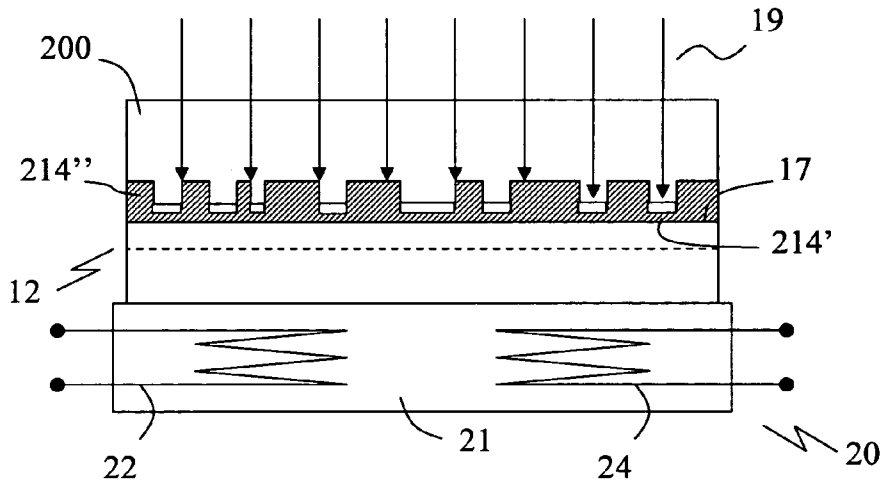


Fig. 11

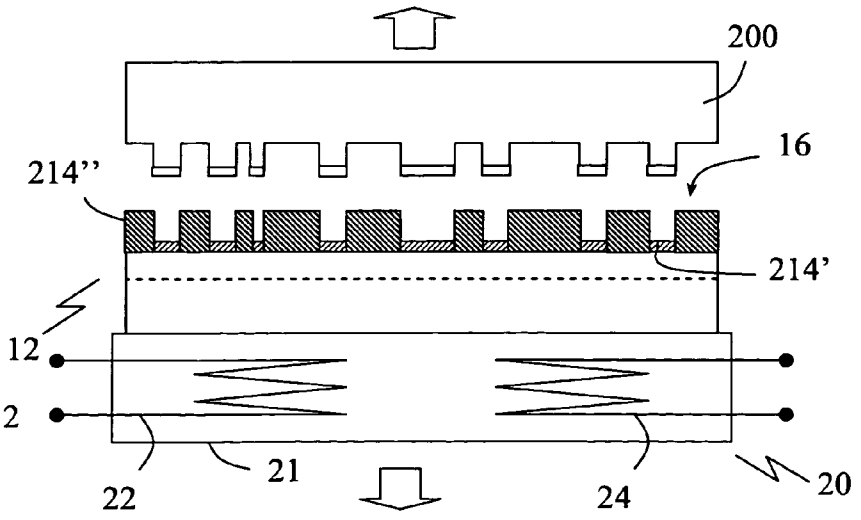


Fig. 12

DEVICE AND METHOD FOR LITHOGRAPHY

FIELD OF THE INVENTION

[0001] The invention relates to a device in connection with the lithography of structures on a micro or nanometre scale. In particular, the invention relates to imprint lithography on substrates or objects.

BACKGROUND

[0002] The trend in microelectronics, as well as in micromechanics, is towards ever smaller dimensions. Some of the most interesting techniques for fabrication of micro and submicro structures include different types of lithography.

[0003] Photolithography typically involves the steps of coating a substrate with a photoresist material to form a resist layer on a surface of the substrate. The resist layer is then exposed to radiation at selective portions, preferably by using a mask. Subsequent developing steps remove portions of the resist, thereby forming a pattern in the resist corresponding to the mask. The removal of resist portions exposes the substrate surface, which may be processed by e.g. etching, doping, or metallisation. For fine scale replication, photolithography is limited by diffraction, which is dependent on the wavelength of the radiation used. For fabrication of structures on a scale of less than 50 nm, such a short wavelength is needed that the material requirements on the optical systems will be major.

[0004] An alternative technique is imprint technology. In an imprint lithography process, a substrate to be patterned is covered by a mouldable layer. A pattern to be transferred to the substrate is predefined in three dimensions on a stamp or template. The stamp is brought into contact with the mouldable layer, and the layer is softened, preferably by heating. The stamp is then pressed into the softened layer, thereby making an imprint of the stamp pattern in the mouldable layer. The layer is cooled down until it hardens to a satisfactory degree followed by detachment and removal of the stamp. Subsequent etching may be employed to replicate the stamp pattern in the substrate. The steps of heating and cooling the combined stamp and substrate can bring about movement in the engaging surfaces due to heat expansion. The larger the area to be imprinted, the larger the actual expansion and contraction, which can make the imprint process more difficult for larger surface areas.

[0005] A different form of imprint technology, generally known as step and flash imprint lithography has been proposed by Willson et al. in U.S. Pat. No. 6,334,960, and also by Mancini et al in U.S. Pat. No. 6,387,787. Similar to the imprint technique briefly described above, this technique involves a template having a structured surface defining a pattern to be transferred to a substrate. The substrate is covered by a layer of polymerisable fluid, into which layer the template is pressed such that the fluid fills recesses in the pattern structure. The template is made from a material which is transparent to a radiation wavelength range which is usable for polymerising the polymerisable fluid, typically UV light. By applying radiation to the fluid through the template, the fluid is solidified. The template is subsequently removed, after which the pattern thereof is replicated in the solid polymer material layer made from the polymerised fluid. Further processing transfers the structure in the solid polymer material layer to the substrate.

[0006] WO 02/067055 to Board of Regents, the University of Texas System, discloses a system for applying step and flash imprint lithography. Among other things, this document relates to production-scale implementation of a step and flash apparatus, also called a stepper. The template used in such an apparatus has a rigid body of transparent material, typically quartz. The template is supported in the stepper by flexure members, which allow the template to pivot about both X and Y axes, which are mutually perpendicular in a plane parallel to the substrate surface to be imprinted. This mechanism also involves a piezo actuator for controlling parallelism and the gap between the template and the substrate. Such a system is, however, not capable of handling large area substrate surfaces in a single imprint step. A step and flash system offered on the market is the IMPRIO 100, provided by Molecular Imprints, Inc, 1807-C West Braker Lane, Austin, Tex. 78758, U.S.A. This system has a template image area of 25×25 mm, and a street width of 0.1 mm. Although this system is capable of handling substrate wafers of up to 8 inches, the imprint process has to be repeated by lifting the template, moving it sideways, and lowering it to the substrate again, by means of an X-Y translation stage. Furthermore, for each such step, renewed alignment as well as new deposition of polymerisable fluid has to be performed. This technique is therefore very time-consuming, and less than optimum for large scale production. Furthermore, besides problems of repeated alignment errors, and high accuracy demands on the translation stage, this technique suffers from the drawback that continuous structures which are larger than said template size cannot be produced. All in all, this means the productions costs may be too high to make this technique interesting for large scale production of fine structure devices.

SUMMARY OF THE INVENTION

[0007] Accordingly, an object of the present invention is to provide methods and means for improving fabrication of structures comprising three-dimensional features on a micro or nanometre scale. In particular, it is an object to provide improved methods and means for transferring a pattern of such structures to substrates having widths of more than one inch, and even for 8 inch diameters, 12 inch diameters, and larger. An aspect of this object is to provide an apparatus and an associated process which is more cost effective and more versatile.

[0008] According to a first aspect, this object is fulfilled by an apparatus for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, said apparatus comprising a first main part and a second main part having opposing surfaces, means for adjusting a spacing between said main parts, support means for supporting said template and substrate in mutual parallel engagement in said spacing with said structured surface facing said surface layer, a radiation source devised to emit radiation into said spacing, a cavity having a first wall comprising a flexible membrane devised to engage said template or substrate, means for applying an adjustable overpressure to a medium present in said cavity, and a heater device having a surface facing said spacing. Due to the flexible membrane, an absolutely even distribution of force is obtained over the whole of the contact surface between the substrate and the template, whereby patterning of large area substrates in a single imprint step is made possible.

[0009] Preferably, said radiation source is positioned in said first main part, devised to emit radiation into said spacing from a first direction, and said heater device is positioned in said second main part, having said surface of the heater device facing said spacing from a second direction, opposite said first direction.

[0010] In one embodiment, said heater device comprises a heating element, connected to an energy source.

[0011] In one embodiment, said heater device comprises a cooling element, connected to a cooling source.

[0012] Preferably, said medium comprises a gas or a liquid.

[0013] In one embodiment, said medium comprises air.

[0014] In one embodiment, said means for applying an adjustable overpressure is arranged to adjust the pressure to 1-500 bar.

[0015] Preferably, said cavity is defined by a part of the surface of said first main part, a flexible seal member arranged in and protruding from said first main part surface, and said membrane which engages said seal member.

[0016] In a preferred embodiment, said membrane is disconnectable from said seal member, and devised to engage said seal member by application of pressure from said second main part.

[0017] Preferably, said membrane is transparent to a wavelength range of said radiation, said radiation source being positioned behind said membrane.

[0018] In one embodiment, said membrane and at least a portion of said surface of said first main part is transparent to a wavelength range of said radiation, said radiation source being positioned behind said portion of said surface of said first main part.

[0019] In a preferred embodiment, said portion of said surface of said first main part is made from quartz, calcium fluoride or any other pressure stable material being transparent to said radiation.

[0020] Preferably, said radiation source is devised to emit radiation at least in a wavelength range of 100-500 nm.

[0021] In a preferred embodiment, said radiation source is air-cooled and devised to emit pulsating radiation with a pulse duration of 0.5-10 μs and a pulse rate of 1-10 pulses per second.

[0022] In one embodiment, said membrane consists of a polymer material.

[0023] In a preferred embodiment, said membrane has a diameter or width of 50-1000 mm.

[0024] In one embodiment, said substrate acts as said membrane.

[0025] According to a second aspect, the object of the present invention is fulfilled by a method for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, comprising the steps of:

[0026] arranging said template and substrate mutually parallel in an imprint apparatus, with said structured surface facing said surface layer, between a stop member and a first side of a flexible membrane;

[0027] heating said surface layer by means of a heater device in said imprint apparatus;

[0028] applying an overpressure to a medium present on a second side of the membrane, opposite to said first side, for imprinting said pattern into said layer; and

[0029] exposing said layer to radiation for solidifying said layer.

[0030] In a preferred embodiment, the method further comprises the step of:

[0031] baking said layer by providing heat from said heater device after said step of exposing said layer to radiation.

[0032] Preferably, said medium comprises a gas or a liquid.

[0033] In one embodiment, said medium comprises air.

[0034] Preferably, the method comprises the step of:

[0035] placing said membrane in direct engagement with said template or said substrate.

[0036] In a preferred embodiment, the method comprises the step of:

[0037] clamping said membrane at a peripheral portion thereof between said stop member and a seal member, thereby defining a peripheral wall for a cavity for said medium.

[0038] Preferably, the method comprises the steps of:

[0039] emitting radiation to said layer through said template, which template is transparent to a wavelength range of a radiation usable for polymerising said fluid; and

[0040] heating said substrate by direct contact with said heater device.

[0041] Alternatively, the method may comprise the steps of:

[0042] emitting radiation to said layer through said substrate, which substrate is transparent to a wavelength range of a radiation usable for polymerising said fluid; and

[0043] heating said template by direct contact with said heater device.

[0044] In a preferred embodiment, the method comprises the step of:

[0045] emitting radiation to said layer through said membrane, which membrane is transparent to a wavelength range of a radiation usable for polymerising said fluid.

[0046] Preferably, the method comprises the step of:

[0047] emitting radiation to said layer through said membrane, and through a transparent wall opposing said membrane, defining a back wall for a cavity for said medium, which back wall and membrane are transparent to a wavelength range of a radiation usable for polymerising said fluid.

[0048] In one embodiment, the step of exposing said layer comprises the step of:

[0049] emitting radiation from a radiation source within a wavelength range of 100-500 nm.

[0050] In a preferred embodiment, the method comprises the steps of:

[0051] air-cooling said radiation source, and emitting pulsating radiation with a pulse duration in the range of 0.5-10 μs and a pulse rate in the range of 1-10 pulses per second.

[0052] In one embodiment, the method comprises the step of:

[0053] using said substrate as said membrane.

[0054] In another embodiment, the method comprises the step of:

[0055] clamping said substrate and template together prior to arranging said template and substrate between said stop member and said flexible membrane.

[0056] In yet another embodiment, the method comprises the step of:

[0057] applying a vacuum between said template and said substrate in order to extract air inclusions from said surface layer prior to exposing said layer to radiation.

[0058] According to a third aspect, the object of the present invention is fulfilled by a method for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, wherein said template includes protrusions defining a pattern, which protrusions have non-transparent layers at outer ends, comprising the steps of:

[0059] arranging said template and substrate mutually parallel in an imprint apparatus, with said structured surface facing said surface layer, between a stop member and a first side of a flexible membrane;

[0060] heating said surface layer by means of a heater device in said imprint apparatus;

[0061] applying an overpressure to a medium present on a second side of the membrane, opposite to said first side, for imprinting said pattern into said layer; and

[0062] exposing said layer to radiation for solidifying said layer at portions between said protrusions.

[0063] In a preferred embodiment, the method further comprises the step of:

[0064] baking said layer by providing heat from said heater device after said step of exposing said layer to radiation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0065] The invention will be described in greater detail below with reference to the accompanying drawings, on which:

[0066] **FIGS. 1-3** schematically illustrate the main process steps for transferring a pattern from a template to a substrate, wherein radiation is applied through a transparent template to solidify a polymerisable fluid on the substrate surface;

[0067] **FIGS. 4-6** schematically illustrate corresponding process steps for transferring a pattern from a template to a substrate, wherein radiation is applied through a transparent substrate to solidify a polymerisable fluid on the substrate surface;

[0068] **FIG. 7** schematically illustrates an embodiment of an apparatus according to the invention, for performing the process as generally described in **FIGS. 1-3** or **4-6**;

[0069] **FIG. 8** schematically illustrates the apparatus of **FIG. 7**, when loaded with a template and a substrate at an initial step of the process;

[0070] **FIG. 9** illustrates the apparatus of **FIGS. 7 and 8**, at an active process step of transferring a pattern from the template to the substrate; and

[0071] **FIGS. 10-12** illustrates an alternative embodiment of an imprint process according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0072] The present invention relates, in general, to a method of transferring a pattern from a template to a substrate, by creating a relief image of a structure on a surface of the template on a surface of the substrate. The surface of the template and the surface of the substrate are in this process arranged generally parallel to each other, and the transfer of the pattern is obtained by pressing the structured template surface into a formable layer disposed on the substrate surface. The formable layer is treated to solidify, such that its shape is forced to resemble the template surface. The template can thereafter be removed from the substrate and its layer, said layer now being an inverted topographical replica of the template. In order to permanent the transferred pattern in the substrate, further processing may be required. Typically, wet or dry etching is performed to selectively etch the surface of the substrate under the solidified layer, whereby the pattern in the solidified layer is transferred to the substrate surface. This much is state of the art, and is well described in prior art documents, such as the aforementioned U.S. Pat. No. 6,334,960.

[0073] **FIGS. 1-3** schematically present the basic process steps of the actual pattern transfer steps, or imprint steps, of an embodiment of the invention.

[0074] In **FIG. 1 a** template **10** is illustrated, the template having a structured surface **11**, in which three-dimensional protrusions and recesses are formed with a feature size in height and width within a range of 1 nm to several μm, and potentially both smaller and larger. The thickness of template **10** is typically between 10 and 1000 μm. A substrate **12** has a surface **17** which is arranged substantially parallel to template surface **11**, with an intermediate spacing between the surfaces at the initial stage shown in **FIG. 1**. The substrate **12** comprises a substrate base **13**, to which the pattern of template surface **11** is to be transferred. Though not shown, the substrate may also include a support layer below the substrate base **13**. In a process where the pattern of template **10** is to be transferred to substrate **12** directly through an imprint in a polymerisable fluid, said fluid may be applied as a surface layer **14** directly onto the substrate

base surface **17**. In alternative embodiments, indicated by the dashed line, a transfer layer **15** is also employed, of e.g. a polymer. Examples of such, and how they are used in the subsequent process of transferring the imprinted pattern to the substrate base **13**, are also described in U.S. Pat. No. 6,334,960. In an embodiment including a transfer layer **15**, substrate surface **17** denotes the upper or outer surface of the transfer layer **15**, which in turn is arranged on the substrate base surface **18**.

[**0075**] Substrate **12** is positioned on a heater device **20**. Heater device **20** preferably comprises a heater body **21** of metal, e.g. aluminium. A heater element **22** is connected to or included in heater body **21**, for transferring thermal energy to heater body **21**. In one embodiment, heater element **22** is an electrical immersion heater inserted in a socket in heater body **21**. In another embodiment, an electrical heating coil is provided inside heater body **21**, or attached to a lower surface of heater body **21**. In yet another embodiment, heating element **22** is a formed channel in heater body **21**, for passing a heating fluid through said channel. Heater element **22** is further provided with connectors **23** for connection to an external energy source (not shown). In the case of electrical heating, connectors **23** are preferably galvanic contacts for connection to a current source. For an embodiment with formed channels for passing a heating fluid, said connectors **23** are preferably conduits for attachment to a heated fluid source. The heating fluid may e.g. be water, or an oil.

[**0076**] Heater body **21** is preferably a piece of cast metal, such as aluminium, stainless steel, or other metal. Furthermore, a body **21** of a certain mass and thickness is preferably used such that an even distribution of heat at an upper side of heater device **20** is achieved, which upper side is connected to substrate **12** for transferring heat from body **21** through substrate **12** to heat layer **14**. For an imprint process used to imprint 2.5" substrates, a heater body **21** of at least 2.5" diameter, and preferably 3" or more, is used, with a thickness of at least 1 cm, preferably at least 2 or 3 cm. For an imprint process used to imprint 6" substrates, a heater body **21** of at least 6" diameter, and preferably 7" or more, is used, with a thickness of at least 2 cm, preferably at least 3 or 4 cm. Heater device **20** is preferably capable of heating heater body **21** to a temperature of 200-300° C., though lower temperatures will be sufficient for most processes.

[**0077**] For the purpose of providing controlled cooling of layer **14**, heater device **20** is further provided with a cooling element **24** connected to or included in heater body **21**, for transferring thermal energy from heater body **21**. In a preferred embodiment, cooling element **24** comprises a formed channel or channels in heater body **21**, for passing a cooling fluid through said channel or channels. Cooling element **24** is further provided with connectors **25** for connection to an external cooling source (not shown). Preferably, said connectors **25** are conduits for attachment to a cooling fluid source. Said cooling fluid is preferably water, but may alternatively be an oil, e.g. an insulating oil, or any other suitable coolant.

[**0078**] Examples of available and usable polymerisable or curable fluids for layer **14** comprise NIP-K17 and NIP-K22 from ZEN Photonics, 104-11 Moonj i-Dong, Yusong-Gu, Daejeon 305-308, South Korea. NIP-K17 has a main component of acrylate, and has a viscosity at 25° C. of about 9.63 cps. NIP-K22 also has a main component of acrylate, and a viscosity at 25° C. of about 5.85 cps. Both substances are devised to cure under exposure to ultraviolet radiation above 12 mW/cm^2 for 2 minutes.

[**0079**] Another example of an available and usable polymerisable fluid for layer **14** is Ormocore from Micro Resist Technology GmbH, Koepenicker Strasse 325, Haus 211, D-12555 Berlin, Germany. This substance has a composition of inorganic-organic hybrid polymer, unsaturated, with a 1-3% photopolymerisation initiator. Viscosity is 3-8 mPas at 25° C., and the fluid may be cured under exposure of radiation with 500 mJ/cm^2 at a wavelength of 365 nm. Other examples of polymerisable materials are mentioned in U.S. Pat. No. 6,334,960.

[**0080**] The thickness of layer **14** when deposited on the substrate surface is typically 10 nm-10 μm, depending on application area. The polymerisable fluid may be applied by spin coating, roller coating, dip coating or similar. A typical advantage with the present invention, compared to the prior art step and flash method, is that the polymer fluid may be spin coated on the entire substrate, which is an advantageous and fast process. The step and flash method, on the other hand, has to use repeated dispensation by dripping on repeated surface portions, since that method is incapable of handling large surfaces in single steps.

[**0081**] The arrows of **FIG. 1** illustrate that the template surface **11** is pressed into surface **16** of the polymerisable fluid layer **14**. At this step, heater device **20** is preferably used to control the temperature of layer **14**, for obtaining a suitable viscosity in the material of layer **14**.

[**0082**] **FIG. 2** illustrates how the structures of template surface **11** has made an imprint in the fluid layer **14**, at which the fluid has been forced to fill the recesses in template surface **11**. In the illustrated embodiment, the highest protrusions in template surface **11** do not penetrate all the way down to substrate surface **17**. This may be beneficial for protecting the substrate surface **17**, and particularly the template surface **11**, from damage. However, in alternative embodiments, such as one including a transfer layer, imprint may be performed all the way down to transfer layer surface **17**. In the embodiment illustrated in **FIGS. 1-3**, the template is made from a material which is transparent to radiation **19** of a predetermined wavelength or wavelength range, which is usable for solidifying a selected polymerisable fluid. Such materials may e.g. be quartz or various forms of polymers, dependent on the radiation wavelength. Radiation **19** is typically applied when template **10** has been pressed into fluid layer **14** with a suitable alignment between template **10** and substrate **12**. When exposed to this radiation **19**, solidification of the polymerisable fluid is initiated, for solidification to a solid body **14'** taking the shape determined by the template **10**. However, heater device **20** is preferably used to provide heat to layer **14'**, for baking layer **14'** to a solid body before separation of template **10** and substrate **12**.

[**0083**] The template **10** is thereafter removed, e.g. by a peeling and pulling process. The formed and solidified polymer layer **14'** remains on the substrate **12**. The various different ways of further processing of the substrate and its layer **14'** will not be dealt with here in any detail, since the invention as such is neither related to such further processing, nor is it dependent on how such further processing is achieved.

[0084] **FIGS. 4-6** schematically present the basic process steps of the actual pattern transfer steps, or imprint steps, of an alternative embodiment of the invention. The only real difference from the embodiment of **FIGS. 1-3** is that in this embodiment the radiation **19** is applied through substrate **12** instead of through template **10**, while the same reference marks have been used. Furthermore, heater device **20** is instead connected to template **10**, for heating layer **14** through template **10**. Heater device **20** of **FIGS. 4-6** otherwise comprises the same features as the heater device of **FIGS. 1-3**, wherefore the same reference markings have been used. No further explanation of the features of **FIGS. 4-6** will therefore be made.

[0085] **FIG. 7** schematically illustrates a preferred embodiment of an apparatus according to the present invention, also usable for carrying out an embodiment of the method according to the present invention. It should be noted that this drawing is purely schematic, for the purpose of clarifying the different features thereof. In particular, dimensions of the different features are not on a common scale.

[0086] The apparatus **100** comprises a first main part **101** and a second main part **102**. In the illustrated preferred embodiment these main parts are arranged with the first main part **101** on top of second main part, with an adjustable spacing **103** between said main parts. When making a surface imprint by a process as illustrated in **FIGS. 1-6**, it may be of great importance that the template and the substrate are properly aligned in the lateral direction, typically called the X-Y plane. This is particularly important if the imprint is to be made on top of or adjacent to a previously existing pattern in the substrate. However, the specific problems of alignment, and different ways of overcoming them, are not addressed herein, but may of course be combined with the present invention when needed.

[0087] The first, upper, main part **101** has a downwards facing surface **104**, and the second, lower, main part **102** has an upwards facing surface **105**. Upwards facing surface **105** is, or has a portion that is, substantially flat, and which is placed on or forms part of a plate **106** which acts as a support structure for a template or a substrate to be used in an imprint process, as will be more thoroughly described in conjunction with **FIGS. 8 and 9**. A heater body **21** is placed on plate **106**, or forms part of plate **106**. Heater body **21** forms part of a heater device **20**, and includes a heating element **22** and preferably also a cooling element **24**, as shown in **FIGS. 1-6**. Heating element **22** is connected through connectors **23** to a energy source **26**, e.g. an electrical power supply with current control means. Furthermore, cooling element **24** is connected through connectors **25** to a cooling source **27**, e.g. a cooling fluid reservoir and pump, with control means for controlling flow and temperature of the cooling fluid.

[0088] Means for adjusting spacing **103** are, in the illustrated embodiment, provided by a piston member **107** attached at its outer end to plate **106**. Piston member **107** is displaceably linked to a cylinder member **108**, which preferably is held in fixed relation to first main part **101**. As is indicated by the arrow in the drawing, the means for adjusting spacing **103** are devised to displace second main part **102** closer to or farther from first main part **101**, by means of a movement substantially perpendicular to the substantially flat surface **105**, i.e. in the Z direction. Displacement may be achieved manually, but is preferably assisted by employing either a hydraulic or pneumatic arrangement. The illustrated embodiment may be varied in a number of ways in this respect, for instance by instead attaching plate **106** to a cylinder member about a fixed piston member. It should further be noted that the displacement of second main part **102** is mainly employed for loading and unloading the apparatus **100** with a template and a substrate, and for arranging the apparatus in an initial operation position. The movement of second main part **102** is, however, preferably not included in the actual imprint process as such in the illustrated embodiment, as will be described.

[0089] First main part **101** comprises a peripheral seal member **108**, which encircles surface **104**. Preferably, seal member **108** is an endless seal such as an o-ring, but may alternatively be composed of several interconnected seal members which together form a continuous seal **108**. Seal member **108** is disposed in a recess **109** outwardly of surface **104**, and is preferably detachable from said recess. The apparatus further comprises a radiation source **110**, in the illustrated embodiment disposed in the first main part **101** behind surface **104**. Radiation source **110** is connectable to a radiation source driver **111**, which preferably comprises or is connected to a power source (not shown). Radiation source driver **111** may be included in the apparatus **100**, or be an external connectable member. A surface portion **112** of surface **104**, disposed adjacent to radiation source **110**, is formed in a material which is transparent to radiation of a certain wavelength or wavelength range of radiation source **110**. This way, radiation emitted from radiation source **110** is transmitted towards spacing **103** between first main part **101** and second main part **102**, through said surface portion **112**. Surface portion **112**, acting as a window, may be formed in available fused silica, quartz, or glass used for CD/DVD mastering.

[0090] In operation, apparatus **100** is further provided with a flexible membrane **113**, which is substantially flat and engages seal member **108**. In a preferred embodiment, seal member **113** is a separate member from seal member **108**, and is only engaged with seal member **108** by applying a counter pressure from surface **105** of plate **106**, as will be explained. However, in an alternative embodiment, membrane **113** is attached to seal member **108**, e.g. by means of a cement, or by being an integral part of seal member **108**. Furthermore, in such an alternative embodiment, membrane **113** may be firmly attached to main part **101**, whereas seal **108** is disposed outwardly of membrane **113**. For an embodiment such as the one illustrated, also membrane **113** is formed in a material which is transparent to radiation of a certain wavelength or wavelength range of radiation source **110**. This way, radiation emitted from radiation source **110** is transmitted into spacing **103** through said cavity **115** and its boundary walls **104** and **113**. Examples of usable materials for membrane **113**, for the embodiment of **FIGS. 7-9**, include polycarbonate, polypropylene, polyethylene. The thickness of membrane **113** may typically be 10-500 μm.

[0091] A conduit **114** is formed in first main part **101** for allowing a fluid medium to pass to a space defined by surface **104**, seal member **108** and membrane **113**, which space acts as a cavity **115** for said fluid medium. Conduit **114** is connectable to a pressure source **116**, such as a pump, which may be an external or a built in part of apparatus **100**. Pressure source **116** is devised to apply an adjustable pres-

sure, in particular an overpressure, to a fluid medium contained in said cavity **115**. An embodiment such as the one illustrated is suitable for use with a gaseous pressure medium. Preferably, said medium is selected from the group containing air, nitrogen, and argon. If instead a liquid medium is used, it is preferred to have the membrane attached to seal member **108**. Such a liquid may be a hydraulic oil.

[**0092**] **FIG. 8** illustrates the apparatus embodiment of **FIG. 7**, when being loaded with a substrate and a template for a lithographic process. For better understanding of this drawing, reference is also made to **FIGS. 1-3**. Second main part **102** has been displaced downwards from first main part **101**, for opening up spacing **103**. As indicated in **FIGS. 1-6**, either the template or the substrate are transparent to radiation of a certain wavelength or wavelength range of radiation source **110**. The illustrated embodiment of **FIG. 8** shows an apparatus loaded with a transparent template **10** on top of a substrate **12**. Substrate **12** is placed with a backside thereof on surface **105** of heater body **21**, placed on or in the second main part **102**. Thereby, substrate **12** has its substrate surface **17** with the layer **14** of polymerisable fluid facing upwards. For the sake of simplicity, all features of heater device **20**, as seen in **FIGS. 1-6** are not shown in **FIG. 8**. Template **10** is placed on or adjacent to substrate **12**, with its structured surface **11** facing substrate **12**. Means for aligning template **10** with substrate **12** may be provided, but are not illustrated in this schematic drawing. Membrane **113** is then placed on top of template **10**. For an embodiment where membrane **113** is attached to the first main part, the step of actually placing membrane **113** on the template is, of course, dispensed with. In **FIG. 8** template **10**, substrate **12** and membrane **113** are shown completely separated for the sake of clarity only, whereas in a real situation they would be stacked on surface **105**.

[**0093**] **FIG. 9** illustrates an operative position of apparatus **100**. Second main part **102** has been raised to a position where membrane **113** is clamped between seal member **108** and surface **105**. In reality, both template **10** and substrate **12** are very thin, typically only parts of a millimetre, and the actual bending of membrane **113** as illustrated is minimal. Still, surface **105** may optionally be devised with a raised peripheral portion at the point where it contacts seal member **108** through membrane **113**, for compensating for the combined thickness of template **10** and substrate **12**.

[**0094**] Once main parts **101** and **102** are engaged to clamp membrane **113**, cavity **115** is sealed. Pressure source **116** is then devised to apply an overpressure to a fluid medium in cavity **115**. The pressure in cavity **115** is transferred by membrane **113** to template **10**, which is pressed towards substrate **12** for imprinting the template pattern in the polymerisable fluid layer **14**, cf. **FIG. 2**. For a polymer material of layer **14** having sufficient viscosity at the operating temperature, typically room temperature between 20 and 25° C., imprint may be made directly. However, certain types of polymers need pre-heating to overcome its glass transition temperature TG, which may be about 60° C. An example of such a polymer is MRL 6000 by Micro Resist Technology. When using such polymers, the apparatus **100**, having combined radiation and heating capabilities, is particularly useful. Heater device **20** is activated to heat polymer layer **14** through substrate **12**, by means of heater body **21**, until TG has been over come. The pressure of the medium in cavity **115** is then increased to 5-500 bar, advantageously to 5-200 bar, and preferably to 5-100 bar. Template **10** and substrate **12** are thereby being pressed together with a corresponding pressure. Thanks to flexible membrane **113**, an absolutely even distribution of force is obtained over the whole of the contact surface between the substrate and the template. The template and the substrate are thereby made to arrange themselves absolutely parallel in relation to one another and, the influence of any irregularities in the surface of the substrate or template being eliminated.

[**0095**] When template **10** and substrate **12** have been brought together by means of the applied fluid medium pressure, radiation source is triggered to emit radiation **19**. The radiation is transmitted through surface portion **112**, which acts as a window, through cavity **115**, membrane **113**, and template **10**. The radiation is partly or completely absorbed in the layer **14** of polymerisable fluid, which thereby is solidified in the perfectly parallel arrangement between template **10** and substrate **12**, provided by the pressure and membrane assisted compression. Radiation exposure time is dependent on the type and amount of fluid in layer **14**, the radiation wavelength combined with the type of fluid, and of the radiation power. The feature of solidifying such a polymerisable fluid is well known as such, and the relevant combinations of the mentioned parameters are likewise known to the skilled person. Once the fluid has solidified to form a layer **14'**, further exposure has no major effect. However, dependent on the type of polymerisable fluid, post-baking at an elevated temperature of 150-160° C. may be necessitated for a time period of 0.5-1 hour. With the apparatus **100** according to the present invention, post-baking may be performed in the imprint machine **100**, which means that it is not necessary to bring the substrate out of the apparatus and into a separate oven. This saves one process step, which makes both time and cost savings possible in the imprint process. For the example of MRL 6000, post-baking is typically performed at 100-120° C. for about 10 minutes. By performing the post-baking step while the template **10** is still held with the selected pressure towards substrate **10**, higher accuracy in the resulting structure pattern in layer **14** may also be achieved, which makes it possible to produce finer structures. Following an exposure time and possibly post-baking under compression, depending on the choice of material and radiation, and dimensions of the polymerisable layer, the pressure in cavity **115** is reduced and the two main parts **101** and **102** are separated from one another. In one embodiment, cooling element **24** of heater device **20** may first be used to cool down the substrate **12** and template **10** before separation. Substrate **12** and template **10** are thereafter separated from one another. After this, the substrate is subjected to further treatment according to what is previously known for imprint lithography.

[**0096**] **FIGS. 8 and 9** illustrate a process similar to that of **FIGS. 1-3**. Again, it should be noted that with a transparent substrate **12**, template **10** may instead be placed on surface **105** of heater body **21**, with substrate on top of template **10**, as shown in **FIGS. 4-6**.

[**0097**] **FIGS. 10-12** illustrates an alternative method of using apparatus **100**, in accordance with an embodiment of the invention. The same reference markings are used for like features as in **FIGS. 1-3**. However, in the process of **FIGS. 10-12**, a transparent template **200** is used, preferably made

from glass or quartz. Template **200** has a structured surface facing substrate **12**, with projecting pattern-defining protrusions **201** having opaque layers **202** covering the outer end surfaces of protrusions **201**. Preferably, layers **202** are metal layers. In a preferred embodiment, template **200** is manufactured by means of first applying a metal mask **202** on selected areas of the template surface, where after an etching process is used for defining grooves between the masked portions. Instead of removing the mask after the etching step, the mask **202** is kept on the template to define the non-transparent outer end surfaces of the template protrusions **201**. By manufacturing template **200** by means of this process, it is also ensured that a near completely even common plane for the outer end surfaces of protrusions **201** is achieved, since the template manufacturing process starts from a flat template body with a plane surface. It should be noted that dimensions illustrated in **FIGS. 1-12** are exaggerated for the sake of easy understanding. For instance, layers **202** may be only a few atomic monolayers thick.

[**0098**] In **FIG. 10**, template **200** is pressed into layer **214** on substrate **12**, preferably by using an apparatus as described with reference to **FIGS. 7-9**. Layer **214** is in this case a Uv-curable negative resist polymer, which may be of any known type. An even pressure is achieved over the entire engaging surfaces of template **200** and substrate **12**, thanks to the imprint technique using a membrane and gas pressure as described above. Preferably, the template **200** is pressed into layer **214** such that the outer ends of protrusions **201** come extremely close to substrate layer **17**, preferably only a few nanometres. In one embodiment, heater device **20** is used for pre-heating layer **214** trough substrate **12**, in order for the polymer of layer **214** to overcome the glass transition temperature.

[**0099**] In **FIG. 11**, radiation **19** is applied through template **200**, towards substrate **12**. Radiation which hits layers **202** is stopped and reflected, and does not reach layer portions **214'**. Radiation which radiates between protrusions **201**, however, will hit layer **214** and start a curing or solidification process in layer portions **214"**. Preferably, baking process is then performed using heater device **20** for completing the curing process.

[**0100**] In the step illustrated in **FIG. 12**, template **200** is separated and removed from template **12**, leaving layer **214** as imprinted. In this shape, substrate **12** is exposed to a negative resist developer fluid. The exact type of fluid may be of any known kind, although the skilled person realises that developer type has to be selected dependent on the resist polymer used. The developer will only remove portions **214'** which were not exposed to radiation, and which remain only as very thin layers at the bottom of the recesses in the polymer layer formed by protrusions **201**. Compared to prior art processes, where an ashing or etching process has to be applied to remove the remaining polymer portions **214'** in the recesses, which is then also cured, this process is considerably easier and faster. Furthermore, ashing or etching of the patterned polymer layer **14** will remove material from all parts of layer **214**, both portions **214'** and **214"**, whereas the proposed method only takes away the portions **214'** which were not exposed to radiation.

[**0101**] One embodiment of the system according to the invention further comprises mechanical clamping means, for clamping together substrate **12** and template **10**. This is particularly preferred in an embodiment with an external alignment system for aligning substrate and template prior to pattern transfer, where the aligned stack comprising the template and the substrate has to be transferred into the imprint apparatus. The system may also contain means for applying a vacuum between template and substrate in order to extract air inclusions from the polymerisable layer of the stacked sandwich prior to hardening of the polymerisable fluid through UV irradiation.

[**0102**] In a preferred embodiment, the template surface **11** is preferably treated with an anti-adhesion layer to prevent the cured polymer layer **14'** from sticking to it after the imprint process. An example of such an anti-adhesion layer comprises a fluorine-containing group, as presented in WO 03/005124 and invented by one of the inventors of the instant invention. The contents of WO 03/005124 are also hereby incorporated by reference.

[**0103**] A first mode of the invention, with a transparent template, which has been successfully tested by the inventors, involves a substrate **12** of silicon covered by a layer **14** of NIP-K17 with a thickness of 1 μm. A template of glass or fused silica/quartz, with a thickness of 600 μm, has been used.

[**0104**] A second mode of the invention, with a transparent substrate, which has been successfully tested by the inventors, involves a substrate **12** of glass or fused silica/quartz covered by a layer **14** of NIP-K17 with a thickness of 1 μm. A template of e.g. nickel or silicon has been used, with a thickness of about 600 μm, though any other suitable non-transparent material can be used.

[**0105**] After compression by means of membrane **113** with a pressure of 5-100 bar for about 30 seconds, radiation source **110** is turned on. Radiation source **110** is typically devised to emit at least in the ultraviolet region below 400 nm. In a preferred embodiment, an air-cooled xenon lamp with an emission spectrum ranging from 200-1000 nm is employed as the radiation source **110**. The preferred xenon type radiation source **110** provides a radiation of 1-10 W/cm^2, and is devised to flash 1-5 μs pulses, with a pulse rate of 1-5 pulses per second. In an alternative embodiment, a continuous mode UV source is used. A window **112** of quartz is formed in surface **104** for passing through radiation. Exposure time is preferably between 1-30 seconds, for polymerising fluid layer **14** into a solid layer **14'**. After successful exposure, second main part **102** is lowered to a position similar to that of **FIG. 8**, following which template **10** and substrate **12** are removed from the apparatus for separation and further processing of the substrate.

[**0106**] The disclosed apparatus and method is particularly advantageous for large area imprint in a single step, and has as such huge benefits over the previously known step and flash method. Thanks to the membrane-transferred fluid pressure, the present invention can be used for one step imprint of substrates of 8 inch, 12 inch, and even larger discs. Even full flat panel displays with sizes of about 400×600 mm and larger can be patterned with a single imprint and exposure step with the present invention. The present invention therefore provides a technique which may for the first time make radiation-assisted polymerisation imprint attractive to large scale production. The invention is usable for forming patterns in a substrate for production of e.g. printed wire boards or circuit boards, electronic circuits,

miniaturised mechanical or electromechanical structures, magnetic and optical storage media etc. The apparatus according to the invention may of course also be used only with the radiation source, or instead only with the heater device.

[0107] The invention is defined by the appended claims.

1. Apparatus for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, said apparatus comprising a first main part and a second main part having opposing surfaces, means for adjusting a spacing between said main parts, support means for supporting said template and substrate in mutual parallel engagement in said spacing with said structured surface facing said surface layer, a radiation source devised to emit radiation into said spacing, a cavity having a first wall comprising a flexible membrane devised to engage said template or substrate, means for applying an adjustable overpressure to a medium present in said cavity, and a heater device having a surface facing said spacing.

2. The apparatus as recited in claim 1, wherein said radiation source is positioned in said first main part, devised to emit radiation into said spacing from a first direction, and said heater device is positioned in said second main part, having said surface of the heater device facing said spacing from a second direction, opposite said first direction.

3. The apparatus as recited in claim 1 or 2, wherein said heater device comprises a heating element, connected to an energy source.

4. apparatus as recited in claim 3, wherein said heater device comprises a cooling element, connected to a cooling source.

5. The apparatus as recited in claim any of the preceding claims, wherein said medium comprises a gas.

6. The apparatus as recited in claim 5, wherein said medium comprises air.

7. The apparatus as recited in any of the preceding claims, wherein said means for applying an adjustable overpressure is arranged to adjust the pressure to 1-500 bar.

8. The apparatus as recited in any of the preceding claims, wherein said cavity is defined by a part of the surface of said first main part, a flexible seal member arranged in and protruding from said first main part surface, and said membrane which engages said seal member.

9. The apparatus as recited in claim 8, wherein said membrane is disconnectable from said seal member, and devised to engage said seal member by application of pressure from said second main part.

10. The apparatus as recited in any of the preceding claims, wherein said membrane is transparent to a wavelength range of said radiation, said radiation source being positioned behind said membrane.

11. The apparatus as recited in claim 8, wherein said membrane and at least a portion of said surface of said first main part is transparent to a wavelength range of said radiation, said radiation source being positioned behind said portion of said surface of said first main part.

12. The apparatus as recited in claim 8, wherein said portion of said surface of said first main part is made from quartz, calcium fluoride or any other pressure stable material being transparent to said radiation.

13. The apparatus as recited in any of the preceding claims, wherein said radiation source is devised to emit radiation at least in a wavelength range of 100-500 nm.

14. The apparatus as recited in claim 10, wherein said radiation source is devised to emit pulsating radiation with a pulse duration of 0.5-10 μs and a pulse rate of 1-10 pulses per second.

15. The apparatus as recited in any of the preceding claims, wherein said membrane is made from a polymer material.

16. The apparatus as recited in any of the preceding claims, wherein said membrane has a diameter or width of 50-1000 mm.

17. The apparatus as recited in any of the preceding claims, where said substrate acts as said membrane.

18. Method for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, comprising the steps of:

arranging said template and substrate mutually parallel in an imprint apparatus, with said structured surface facing said surface layer, between a stop member and a first side of a flexible membrane;

heating said surface layer by means of a heater device in said imprint apparatus;

applying an overpressure to a medium present on a second side of the membrane, opposite to said first side, for imprinting said pattern into said layer; and

exposing said layer to radiation for solidifying said layer.

19. The method as recited in claim 18, further comprising the step of:

baking said layer by providing heat from said heater device after said step of exposing said layer to radiation.

20. The method as recited in claim 18 or 19, wherein said medium comprises a gas.

21. The method as recited in claim 20, wherein said medium comprises air.

22. The method as recited in any of the preceding claims 18-21, comprising the step of:

placing said membrane in direct engagement with said template or said substrate.

23. The method as recited in claim 18, comprising the step of:

clamping said membrane at a peripheral portion thereof between said stop member and a seal member, thereby defining a peripheral wall for a cavity for said medium.

24. The method as recited in claim 18, comprising the steps of:

emitting radiation to said layer through said template, which template is transparent to a wavelength range of a radiation usable for polymerising said fluid; and

heating said substrate by direct contact with said heater device.

25. The method as recited in claim 18, comprising the steps of:

emitting radiation to said layer through said substrate, which substrate is transparent to a wavelength range of a radiation usable for polymerising said fluid; and

heating said template by direct contact with said heater device.

26. The method as recited in any of the preceding claims **18-25**, comprising the step of:

emitting radiation to said layer through said membrane, which membrane is transparent to a wavelength range of a radiation usable for polymerising said fluid.

27. The method as recited in any of the preceding claims **18-26**, comprising the step of:

emitting radiation to said layer through said membrane, and through a transparent wall opposing said membrane, defining a back wall for a cavity for said medium, which back wall and membrane are transparent to a wavelength range of a radiation usable for polymerising said fluid.

28. The method as recited in any of the preceding claims **18-27**, wherein the step of exposing said layer comprises the step of:

emitting radiation from a radiation source within a wavelength range of 100-500 nm.

29. The method as recited in claim 28, comprising the steps of:

emitting pulsating radiation with a pulse duration in the range of 0.5-10 μs and a pulse rate in the range of 1-10 pulses per second.

30. The method as recited in any of the preceding claims **18-29**, comprising the step of:

clamping said substrate and template together prior to arranging said template and substrate between said stop member and said flexible membrane.

31. The method as recited in claim 18, comprising the step of:

applying a vacuum between said template and said substrate in order to extract air inclusions from said surface layer prior to exposing said layer to radiation.

32. Method for transferring a pattern from a template having a structured surface to a substrate carrying a surface layer of a radiation polymerisable fluid, wherein said template includes protrusions defining a pattern, which protrusions have non-transparent layers at outer ends, comprising the steps of:

arranging said template and substrate mutually parallel in an imprint apparatus, with said structured surface facing said surface layer, between a stop member and a first side of a flexible membrane;

heating said surface layer by means of a heater device in said imprint apparatus;

applying an overpressure to a medium present on a second side of the membrane, opposite to said first side, for imprinting said pattern into said layer; and

exposing said layer to radiation for solidifying said layer at portions between said protrusions.

33. The method as recited in claim 32, further comprising the step of:

baking said layer by providing heat from said heater device after said step of exposing said layer to radiation.

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