Method and Device for Embossing Structures

Specification

The invention relates to a method ~~according to Claim 1~~ as well as a device ~~according to Claim 5~~ for embossing structures.

The production of structures in the micrometer and/or nanometer range is carried out to an increasing extent using imprint lithography. In recent years, imprint lithography has always been able to hold its own compared to photolithography. The merits of imprint lithography primarily lie in the possibility of the production of structures in the nanometer range, whose production would not be at all feasible by means of photolithography or would be extremely expensive. Now, patterns in the nanometer and/or micrometer range can be produced with high precision and accuracy in a mass process on the surfaces of substrates. Although the merits of imprint lithography lie primarily in the production of structures in the nanometer range, there is also a very large area of application in the micrometer range for the imprint technologies, most particularly in the lens-embossing technique.

The lens-embossing techniques can be used in embossing techniques for the production of so-called monolithic lens wafers. The production process is called monolithic lens molding (English: monolithic lens molding, MLM, for short). With this technique, several lenses are produced as part of

to allow a corresponding embossing process to take place in a vacuum. To this end, the corresponding chamber has to be evacuated before each embossing process. After successful embossing, the chamber would again be ventilated. These processes are correspondingly time-intensive and therefore very expensive.

Another problem, which primarily occurs in the dispensing of drops of embossing material for the production of single lenses distributed on a carrier substrate, is the symmetry of individual lenses. A poorly-positioned drop of embossing material on the carrier substrate and/or a poor approach of the embossing die and therefore the embossing structures, relative to the drops of embossing material, lead to asymmetric lens shapes.

The flowing of the embossing material, which can be attributed in particular to the adhesion property between the embossing material and the corresponding surface, represents another problem.

~~It is therefore the object of this invention to solve one or more of the above-mentioned technical problems with~~ Embodiments of the present invention provide a method and/or a device ~~according to the subsequent description~~ for embossing structures.

~~This object is achieved with the features of Claims 1 and 5. Advantageous further developments of the invention are indicated in the subclaims.~~

According to an aspect of the present invention, there is provided a method for embossing single lenses with at least one microstructure or nanostructure on a carrier substrate with an embossing die that has at least one embossing structures with the following steps, in particular the following sequence: Aligning each embossing structure of the embossing die relative to a metering device. Metering an embossing material in each embossing structure by means of the metering device. At least partial hardening of

the embossing material and embossing of the embossing material, characterized in that the embossing structures point in a gravitational direction at least in the case of the metering, wherein the gravitation provides that a convex embossing material surface is designed in the direction of the carrier substrate, wherein a point contact of the embossing material with the carrier substrate is made possible by approaching of the die in the direction of the carrier substrate, wherein because of another approach of the embossing die in the direction of the carrier substrate, the contact surface of the embossing material surface is enlarged continuously with the carrier substrate.

All combinations that consist of at least two of the features indicated in the specification, the claims and/or the figures also fall within the scope of the invention. In the indicated ranges of values, values as boundary values that lie within the above-mentioned limits are also to be

considered as disclosed and can be claimed in any combination.

~~The invention is~~ Embodiments of the present invention are based on the idea of solving the above-mentioned technical problems by dispensing an embossing material in embossing structures against the force of gravity, in particular by aligning the dispensing direction of a metering device against the force of gravity, i.e., against a gravitational direction G and/or by orienting embossing structures, in particular an axis of symmetry of the respective embossing structure, parallel to the force of gravity and/or pointing in the gravitational direction G.

~~The~~Embodiments of the invention therefore in particular deal~~s~~ with a method and a unit for avoiding gas inclusions between the surface of the embossing structure of the embossing die and the embossing material as well as a method for continuous and/or controlled hardening of the embossing material.

In addition, embodiments of the invention deal~~s~~ with a method and a unit that ensure that the embossing material performs self-assembly into a preset form. This self-assembly is a direct result of several physical effects.

Another ~~aspect according to~~ embodiment of the invention is the prevention or at least the suppression of the lateral flowing of the embossing material.

~~The~~Embodiments of the invention ~~has~~have the advantages of a self-assembly of the embossing material in the corresponding embossing structure, a savings of material by a targeted and exactly calculated dispensing/metering, a

symmetrification and uniform distribution of the embossing material in the embossing structures, a locally limited edge layer hardening of the embossing material, which does not inhibit - or prevent - a deformation of the edge layer against set embossing material.

In addition, a flowing of the embossing material in the lateral direction by gravitation is prevented with the dispensing method according to embodiments of the invention. The gravitation according to embodiments of the invention provides that a convex embossing material surface is designed in the direction of the carrier substrate, which prevents a lateral spilling of the embossing material. In addition, because of the convex embossing material surface, a point contact of the embossing material with the substrate surface is made possible. Because of another approach of the embossing die in the direction of the carrier substrate, the contact surface of the embossing material surface is enlarged continuously with the carrier substrate, starting from the contact point, and thus prevents inadvertent gas inclusions in the simplest manner.

~~The~~Embodiments of the invention describe~~s~~ in particular a method and a unit for embossing micrometer-size and/or nanometer-size structures. ~~One idea according to~~Embodiments of the invention consist~~s in~~ of an efficient, simplified, inexpensive method for locally limited and defect-free distribution of an embossing material. The dispensing of the embossing material in the embossing structures of the embossing die in this case is carried out according to embodiments of the invention against the force of gravity. The filling of the embossing structures of the embossing die is not only made possible but rather also supported by the adhesive forces between the surface of the embossing structure and the embossing material. The adhesion, the curvature of the embossing structures, as well as the pressure generated by a nozzle result in tangential forces on the embossing material, which results in a

wetting of the embossing structure surface. During the wetting process, any gas that exists in the environment is pushed ahead of the wave of embossing material. A possible formation of undesired gas inclusions therefore does not occur. In addition, the embodiment and method according to embodiments of the invention prevent by gravitation a flowing of the embossing material in the lateral direction, i.e., along the embossing structure surface.

~~According to another aspect according to the invention,~~ Another embodiment of the invention describes in particular a unit for dispensing an embossing material in an embossing structure of an embossing die. The embossing structures of the embossing die are located during the filling above a substrate, on which the embossing process is to be performed. The unit according to embodiments of the invention therefore consists at least of a sample holder, an embossing die, as well as a dispensing device, which can dispense/meter embossing material against the force of gravity.

In the following sections, the two basic kinds of dies for embossing lithography are to be presented.

In imprint technology, a distinction is made between two kinds of embossing dies, the hard dies and the soft dies. Any die process can theoretically be performed with a hard die or a soft die. There are, however, several technical and financial reasons to use the hard die itself only as a so-called master die and to mold a soft die from this master die, whenever necessary, which soft die then is used as an actual structural die. The hard die is thus a negative of the soft die. The hard die is required only for the production of several

soft dies. Soft dies can be distinguished by different chemical, physical and technical parameters of hard dies. A differentiation based on the elasticity behavior would be conceivable. Soft dies have a deformation behavior predominantly based on entropy elasticity, and hard dies have a deformation behavior predominantly based on energy elasticity. In addition, the two kinds of dies can be distinguished by, for example, their hardness. Hardness is the resistance that a material puts up against a penetrating body. Since hard dies predominantly consist of metals or ceramics, they have correspondingly high hardness values. There are different possibilities for indicating the hardness of a solid body. A very commonly used method is the indication of hardness according to Vickers. Hard dies according to embodiments of the invention preferably have a Vickers hardness of more than 500 HV.

Hard dies specifically have the advantage that they can be manufactured directly by suitable processes such as electron beam lithography or laser beam lithography from a component made of a material with high strength and a high degree of rigidity. Such hard dies have a very high level of hardness and are thus more or less wear-resistant. The high level of strength and wear resistance, however, are primarily accompanied by high costs, which are necessary with respect to manufacturing a hard die. Even though the hard die can be used for hundreds of embossing steps, even it will experience significant wear over time. In addition, the demolding of the hard die from the embossing material is technically difficult. Hard dies have a relatively high flexing resistance. They are not especially readily deformable, i.e., in the ideal case, they have to be lifted in the normal direction. In the demolding of the hard die after the

embossing process, in this case it can regularly result in a destruction of the embossed nanostructures and/or microstructures, since the hard die has a very high degree of rigidity and therefore can destroy the microstructures and/or nanostructures of the just-molded embossing material. In addition, substrates can have defects that can subsequently lead to damage or destruction of the hard die. If the hard die is only used as a master die, however, the molding process of the soft die from the master die is very readily controllable and is associated with very little wear of the master die.

Soft dies can be manufactured very simply by replication processes from the master die (hard die). In this case, the master die represents the negative that corresponds to the soft die. The soft dies are thus embossed on the master die, subsequently demolded, and then are used as structural dies for embossing the die structures on a substrate. Soft dies can be removed more simply, gently and less problematically from the embossing material than hard dies. In addition, any number of soft dies can be molded by a master die. After a soft die has undergone a certain wear and tear, the soft die is discarded and a new die is formed from the master die.

~~For the~~ In embodiments ~~according to~~ of the invention, hard dies are preferably used.

The sample holder is preferably a vacuum sample holder. The use of an electrostatic sample holder, a sample holder with magnetic or electrical attachment, or a

sample holder with a changeable adhesion property or with a corresponding mechanical clamping would also be conceivable.

On its embossing side, the embossing die has in particular several embossing structures that are preferably distributed over the entire embossing surface of the embossing side and are in particular arranged in regular fashion. In this case, for example, these can be, for example, concave lens shapes that are used as negatives of the convex lenses to be embossed in a corresponding manner. The diameter of the lenses is especially preferably large in comparison to the depth of the lens. The ratio of the diameter to the depth of the lens shapes is in particular larger than 1, preferably larger than 10, more preferably larger than 20, most preferably larger than 50, and with utmost preference larger than 100. A correspondingly large ratio ensures the continuous lateral inflow and freedom from bubbles of the embossing material that is unimpeded according to embodiments of the invention. As an alternative, a structure, especially a lens shape in which the diameter is smaller than the depth, is conceivable. The ratio of the depth to the diameter of the lens shapes is then in particular larger than 1, preferably larger than 10, more preferably larger than 20, most preferably larger than 50, and with utmost preference larger than 100.

The embossing material is hardened according to embodiments of the invention in particular by chemical and/or physical processes. In particular, the embossing material is hardened either by electromagnetic radiation and/or by temperature.

Preferably, the hardening by electromagnetic radiation is carried out with special preference by UV radiation. In this case, the embossing die is preferably transparent to the necessary

electromagnetic radiation, when the embossing material is to be hardened from the embossing die side. This is the case according to embodiments of the invention in particular with gradual hardening of the embossing material.

Behind the embossing die (i.e., on the side facing away from the embossing structures), a corresponding radiation source is preferably arranged. The embossing die is therefore in particular transparent in a wavelength range of between 5,000 nm and 10 nm, preferably between 1,000 nm and 100 nm, more preferably between 700 nm and 200 nm, and most preferably between 500 nm and 300 nm. The optical transparency of the embossing die is in this case greater than 0%, preferably greater than 20%, more preferably greater than 50%, most preferably greater than 80%, and with utmost preference greater than 95%.

If the embossing material is to be thermally hardened by the embossing die, the embossing die primarily has very high heat conductivity in order to transport the heat on the back side of the die as quickly as possible to the embossing material. In this case, the heat conductivity of the embossing die is in particular greater than 0.1 W/(m*K), preferably greater than 1 W/(m*K), preferably greater than 10 W/(m*K), most preferably greater than 100 W/(m*K), and with utmost preference greater than 1,000 W/(m*K).

In addition, the embossing die should have a correspondingly low heat capacity for as little thermal inertia as possible. The specific heat capacities should be less than 10 kJ/(kg*K), preferably less than 1 kJ/(kg*K), more preferably less than 0.1 kJ/(kg*K), most preferably less than 0.01 kJ/(kg*K), and with utmost preference less than 0.001 kJ/(kg*K). As a result,

temperature changes of the heat source can be relayed as quickly as possible to the embossing material.

The hardening temperature of the embossing material is in particular greater than 25°C, preferably greater than 100°C, more preferably greater than 250°C, and with utmost preference greater than 500°C. ~~The~~Embodiments of the invention can be carried out for special applications at hardening temperatures of more than 700°C, preferably more than 800°C, more preferably more than 900°C, and most preferably around 1,000°C, in particular with a use of embossing materials, in which a sintering process is performed.

A hardening of the embossing materials via a radiation source in or on the sample holder is also conceivable according to embodiments of the invention. All features mentioned for the embossing die accordingly apply analogously for the sample holder, in particular as an alternative or additional radiation source. An additional source in the sample holder can primarily accelerate and promote the complete hardening of the embossing materials at the end of any process according to embodiments of the invention. A special efficiency and homogeneity, in particular, however, a flexibility in the case of the control of the hardening process, is achieved primarily by a simultaneous two-sided hardening.

Another advantage of the metering/dispensing of the embossing material according to embodiments of the invention against gravitation (force of gravity acting on the embossing material during metering/dispensing) consists in that, in any of the two above-mentioned methods according to embodiments of the invention, gravitation ensures that the embossing material does not run in the lateral direction.

Another ~~aspect~~ embodiment according to the invention for the dispensing of the embossing material against gravitation is an adhesive force between the embossing material and the embossing structure surface, which, in particular by material selection and/or surface treatment, is set greater than the force of weight or the weight of the embossing material. The ratio between the force of weight and the adhesive force is in this case smaller than 1, preferably smaller than 0.1, more preferably smaller than 0.01, most preferably smaller than 0.001, and with utmost preference smaller than 0.0001.

In this case, it is noticed in particular that there is as little adhesion as possible so that in the last process step, the demolding step, as simple a demolding of the embossing die as possible can be carried out. The adhesive energy surface density, adhesive force for short, is in particular less than 1 J/m2, more preferably less than 0.1 J/m2, more preferably less than 0.01 J/m2, most preferably less than 0.001 J/m2, and with utmost preference less than 0.0001 J/m2.

The viscosity of the embossing material is preferably very low, so that a correspondingly simple and fast distribution of the embossing material in the lens shape can be carried out. The viscosity is in particular less than 100,000 mPas, preferably less than 1,000 mPas, more preferably less than 5 mPas, and most preferably less than 1 mPas.

The dispensed volumes of the embossing material are in particular larger than 0.0001 µl, preferably larger than 0.001 µl, most preferably larger than 0.1 µl, most preferably larger than 10 µl, and with utmost preference larger than 500 µl.

According to embodiments of the invention, it is conceivable in particular that the device according to embodiments of the invention and the method for the production of a monolithic lens wafer according to embodiments of the invention are used by enough embossing material being deposited that the embossing materials in the individual lens shapes are laterally combined with one another even before the embossing on the substrate. In particular by metering the embossing material for each lens shape so that no contact of the embossing materials among one another occurs, the embodiment ~~according to~~ of the invention for simultaneous embossing of single lenses can be used on a substrate. If an embossing die that is smaller than the substrate on which the lenses are to be embossed is used according to embodiments of the invention, the process according to embodiments of the invention is correspondingly repeated often in order to provide the entire substrate with lenses. Accordingly, the embossing technique would be referred to as a step-and-repeat embossing technique.

~~The embodiment according to~~ Embodiments of the invention can be applied in particular to the above-described embossing techniques.

The unit according to embodiments of the invention can preferably be installed in a process chamber which can be hermetically sealed from the environment. Thus, an evacuation of the process chamber and/or a ventilation of the process chamber is made possible with any gas or gas mixture. In this case, the process chamber can be evacuated at pressures of less than 1 bar, preferably less than 10^{-3} mbar, more preferably less than 10^{-5} mbar, and most preferably less than 10^{-8} mbar. The use of a vacuum primarily has the advantage that as a result, the undesired gas inclusion can be completely suppressed or at least improved, since even before (preferred embodiment)

and/or during and/or after the embossing material is deposited, any and all kinds of gas are removed from the process chamber.

The process chamber can be flushed according to embodiments of the invention in particular with any gas or gas mixture. This is primarily then advantageous when the embossing is not to take place under vacuum. High volatility of the embossing material at low ambient pressure would be a possible reason – but not the only reason - for the elimination of a vacuum. The slight volatility that is characterized by a high vapor pressure can contribute decisively to the contamination of the process chamber. The gas that is used should then have as little interaction with the embossing material as possible. Flushing with an inert gas, which does not interact with the embossing material, would be especially preferred. In particular, the use of

- Argon and/or
- Helium and/or
- Carbon dioxide and/or
- Carbon monoxide and/or
- Nitrogen and/or
- Ammonia and/or
- Hydrogen

would be conceivable.

When embossing materials are used that are to be influenced by a gas, preferably correspondingly reactive gases are used. In quite special embodiments, it is conceivable that the process chamber is exposed to an overpressure. In this case, the pressure in the process chamber is greater than 1 bar, preferably greater than 2