Method for Microcontact Embossing

Specification

This invention relates to a method for microcontact embossing according to Claim 1 or 2.

The present state of the art for microstructuring and/or nanostructuring of surfaces primarily comprises photolithography and different embossing techniques. Embossing techniques work either with hard or soft dies. In recent times, primarily embossing lithography techniques have predominated and have eclipsed conventional photolithography techniques. Among embossing lithography techniques, primarily the use of so-called soft dies is becoming more and more popular. The reason lies in the easy production of the dies, efficient embossing processes, very good surface properties of the respective die materials, the low costs, the reproducibility of the embossing product, and primarily in the possibility of the elastic deformation of the die during demolding. In soft lithography, a die that consists of an elastomer with a microstructured or nanostructured surface is used in order to produce structures in the range of 20 nm up to > 1,000 µm. Embossing lithography techniques can be roughly divided into hot embossing, nanoimprint lithography, and nanocontact or microcontact embossing. During hot embossing, the

die is pressed mainly with application of force in a (heated) embossing material. In nanoimprint lithography, a very finely structured die is brought into contact with the embossing material. Although forces are also used in this method, the receiving of embossing material into nanometer- or micrometer-sized structures by capillary action is a driving force of the embossing process. With microcontact embossing, the structured die is not pressed by force into an embossing material but rather transfers a substance located on the surface of its structures onto another surface.

There are six known microcontact embossing methods:

- Microcontact and/or nanocontact pressing (μ/nCP)
- Replica casting (REM)
- Microtransfer molding (μTM) or nanoimprint lithography (NIL),
- Microforming in capillaries (MIMIC)
- Solvent-supported microforms (SAMIM), and
- Phase shift lithography.

Elastomer structural dies are produced as negatives of a master. A master die is a hard die made of metal or ceramic, which is produced at one time by correspondingly expensive processes. Any number of elastomer dies can then be produced from the master. The elastomer dies make possible a conformable, uniform contact across large surfaces. They are easy to separate from their rigid master die as well as from the embossing products. In addition, elastomer dies have a low surface tension for an easy and simple separation from die and substrate. The material combinations of the structural die and the embossing material cause technical problems, whereby the important factors are, i.a., a long service life

or extended usability of the structural die and an exact transfer of the microstructures and/or nanostructures.

It is therefore the object of this invention to indicate a microcontact embossing method with which a long-lived structural die is indicated, which is suitable for an exact transfer of the microstructures and/or nanostructures to large surfaces.

This object is achieved with the features of Claims 1 and 2. Advantageous further developments of the invention are indicated in the subclaims. 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 describes a method in which for microcontact embossing, at least predominantly silane or at least one silane derivative or a molecular component that at least predominantly consists of organic molecules is used as embossing material.

The invention thus relates to a method that makes it possible to deposit material in a structured form directly and specifically onto a target surface of a substrate. In this case, the structural values shift in the lateral direction according to the invention in the micrometer and/or nanometer range. The deposition process is based on bringing the surface into contact with a structured die. In this case, embossing material that adheres to the structural die is transferred specifically and in a structured form onto the target surface.

The invention also deals with the use of a structural die that consists of a suitable die material according to the invention for contact embossing of any molecular component.

An advantageous further development of the invention is based on a special die structure, which makes possible an automatic supply of material for the embossing material.

The application of the die material according to the invention and/or the die structure according to the invention in combination with embossing material matched to the die material according to the invention on selected substrate surfaces according to the invention and/or for the production of a specific group/type of end products has proven especially advantageous.

The invention makes possible the production of virtually any structured surfaces with extremely small thicknesses that consist of the above-mentioned components according to the invention. In this case, the structures are very economically produced in large-scale production with high yield and based on the simple process run and the low number of process steps resulting therefrom, since the structural die according to the invention can be used for a number of die processes and on large surfaces. When using the die structure according to the invention, the embossing material supply for the embossing material is carried out in particular automatically and/or continuously, which in turn increases the output of the process and reduces the costs.

The disclosed embodiments of the structural die according to the invention, in particular the die materials that are used, offer the advantage of not contaminating the embossing material as well as not altering the latter either from the chemical standpoint or from the biological standpoint or influencing their

reactivity. In this case, the embossing materials simultaneously make possible a significantly improved production process of the die required for the contact pressure.

The invention thus also relates to a method to transfer a molecular component by a contact process from a structural die onto a target surface of an in particular large-area, preferably flat, substrate. In special embodiments, the transfer of a molecular component also onto a structured target surface can take place. This primarily makes possible the use of the microcontact embossing for the creation of structured surfaces in the third dimension. In this case, the invention is based on the idea that a structured die, which was produced from a material that is suitable according to the invention, attaches/adheres a molecular component to projections of the structure of the structural die by adhesive forces and/or diffusion into the die material and/or diffuses into a certain area in the die material. The molecular component is to be moved at the surface of the structures of the structural die onto a target surface according to the invention. By an approach of the die to the target surface, the molecular component comes into contact with the target surface. After the contact of the target surface with the molecular component, the latter is at least partially transferred onto the target surface. This is to be understood in the sense that at least some of the molecules that adhere to the raised die structures are transferred. The mechanisms of the transfer are in this case diverse.

The transfer of a molecular component as a structure onto a target surface is referred to as contact pressure. In this case, the dimensions of the structures that are to be transferred lie in the nanometer and/or micrometer range, by which the method is referred to more precisely as microcontact pressure, which also encompasses nanocontact pressure. The contact embossing method

has the advantage of producing razor-thin structured surfaces, even up to monolayers. According to the technique, no molding of the die structure is thus performed in an embossing material, but rather a molecular component, in particular silane and/or silane derivatives, which is found at least at the projections of the die, is transferred.

In an alternative embodiment of this invention, it is provided that the molecular component has at least one or more of the structures mentioned below:

- Enzymes,
- Alkaloids,
- Lipids,
- Hormones,
- Pheromones,
- Vitamins,
- Carbohydrates,
- Peptides,
- Nucleic acids,
- DNA or DNA strands,
- Cells,
- Proteins or peptides,
- Alkanes, alkenes, alkines, aromatic compounds
- Graphene.

There is preferably a transfer by differences in adhesive force between the molecular component and the target surface, on the one hand, and the adhesive force between the molecular component and the die surface, on the other hand. In a preferred embodiment, the adhesive forces between the target surface and the molecular component are therefore greater than between the

surface of the structured die and the molecular component. Preferably, the ratio of the above-mentioned adhesive forces is greater than 1, preferably greater than 2, more preferably greater than 5, even more preferably greater than 10, most preferably greater than 100, and with utmost preference greater than 1,000.

In another embodiment, the detachment of the molecular component from the die surface is carried out by an electric charging of the die surface. According to the invention, the electrical potential is altered by the charging of the die surface in such a way that the adhesion to the molecular component that is to be transferred is less than the adhesion of the molecular component to the target surface. An electric charging of the target surface, which alters the electrical potential in such a way that the adhesion between the molecular component and the target surface is greater than the adhesion between the molecular component and the die surface, would also be conceivable.

In another embodiment, the structural die is at least partially porous, and the detachment of the molecular component from the die surface is preferably carried out by a pressure, which is elevated relative to the environment, in the pores in the interior of the porous structural die. In this case, the elevated pressure can be charged by any type of fluid, i.e., liquids and/or gases. Preferably, the fluid is the molecular component that is to be deposited, thus making the structural die itself a reservoir for the molecular component. The ratio between the ambient pressure and the pressure in the die is in this case greater than 1, preferably greater than 1.5, more preferably greater than 2.0, most preferably greater than 10, and with utmost preference greater than 100.

In another embodiment, the detachment of the molecular component is done via a chemical process, which selectively attacks the contact surface between the molecular component and the die surface, while the contact surface between the molecular component and the target surface is not attacked.

In another embodiment, the detachment of the molecular component is done via a thermal process by the die according to the invention being heated and/or cooled to a dissolving temperature, so that the molecular component is detached from the die surface, while the adhesion to the target surface is maintained.

In another embodiment, the detachment of the molecular component is done via an electric and/or magnetic field, which weakens the contact surface between the molecular component and the die surface, while the adhesion to the target surface is maintained.

According to the invention, a combination of the disclosed transfer method of the molecular component is also possible.

In a preferred embodiment, the embossing material is fed exclusively via the die. Since a continuous material flow from the back side of the die takes place, some monolayers of the molecular component always adhere over one another. The adhesion between the molecular component and the target surface is therefore greater according to the invention than the cohesion between the individual layers of the molecular component itself. As a result, the detachment of the molecular component is carried out at least predominantly in the form of monolayers.

According to an advantageous embodiment, the die is preferably elastically deformable, i.e., a so-called "soft stamp." A soft stamp is present as soon as the die structure is produced from a soft material. The lateral stability of the soft stamp is preferably ensured by means of a carrier that is arranged, and preferably attached, behind it. The carrier is formed in particular from ceramic or metal. The elasticity is defined in general by a stiffness tensor. Since these materials exhibit homogeneous-isotropic elastic behavior in good approximation, the elastic behavior can be described by the two physical parameters of the modulus of elasticity and Poisson's number. The modulus of elasticity of the disclosed soft stamp is between 10^{-3} MPa and 100 MPa, preferably between 10^{-2} MPa and 10 MPa, more preferably between 10^{-1} MPa and 1 MPa, and most preferably between 0.5 MPa and 0.8 MPa.

According to the invention, the E-modulus for PFPE is in particular between 3 and 40 MPa. According to the invention, the E-modulus for PDMS is approximately 0.75 MPa.

Poisson's number is between 0.01 and 0.5, preferably between 0.1 and 0.5, more preferably between 0.2 and 0.5, and most preferably between 0.25 and 0.5.

With nanocontact and/or microcontact embossing, "soft stamps" are preferred, since the latter are able to become deformed during the transfer process and can therefore be matched to the waviness and/or roughness of the target surface. If a "hard stamp" were to be used, the die surfaces, as well as the target surfaces, would have to have an extremely slight waviness and/or roughness, which technically can be produced only with difficulty or only at considerable expense.

The structural die is therefore preferably a "soft stamp," i.e., a soft die. The die preferably consists of a material that is easily deformable, elastic, acid- and/or base-resistant, wear-resistant, inert, and porous and that can be produced economically. The die material is preferably a polymer. If the structural die is formed from a polymer, the latter can be hardened in particular by thermal processes and/or light irradiation. In addition, a die that is used simultaneously as a reservoir for the molecular component would be preferred. The reservoir is made possible by a corresponding porosity of the die. The open porosity of the die is in particular between 0 (i.e.: greater than 0) and 50%, preferably between 0 and 40%, more preferably between 0 and 30%, most preferably between 0 and 20%, and with utmost preference between 0 and 10%. By receiving the molecular component, the die behaves in part like a sponge. Swelling of the die results. The material transport of the molecular component can therefore take place through the die from a reservoir located behind the die or the die itself can be used as a reservoir because of its absorbency. The corresponding underlying physical phenomena of the material transport in and/or through the die are therefore the diffusion and the fundamental laws of flow dynamics. In this case, diffusion occurs as soon as when the molecular component is able to go from one side of the die to the other, or to be absorbed by one side of the die, such as by a sponge. In special cases, diffusion can also be present when the porosity of the die is low; nevertheless, the molecular component has the possibility of moving, however, based on the microstructure of the die material.

In a special embodiment, the die consists of a perfluoropolyether (PFPE).

In another special embodiment, the die consists of a polydimethylsiloxane (PDMS).

The structural die is preferably transparent in order to load the molecular component that is to be deposited through the structural die with electromagnetic radiation, in particular to start corresponding physical and/or chemical processes shortly before and/or during and/or after the transfer of embossing material onto the target surface. This applies analogously to thermal conductivity, electrical conductivity, primitivity and permeability, should the above-mentioned chemical and/or physical processes be started by heat, electric current, electric fields or magnetic fields.

According to the invention, the structural die is either a structural die that can move in space by x-y-z translation, or a roller die. A roller die is defined as a preferably seamless, structured roller that transfers its surface structure by a rotational movement onto the target surface and is suitable for the production of "continuous products."

Additional advantages, features and details of the invention follow from the description below of embodiments that are preferred and based on the drawings; the latter in each case show in diagrammatic view:

Figure 1 a diagrammatic cross-sectional view of a first embodiment of this invention,

Figure 2 a diagrammatic cross-sectional view of a second embodiment of this invention,

Figure 3 a diagrammatic cross-sectional view of a third embodiment of this invention,

Figure 4 a diagrammatic cross-sectional view of a fourth embodiment of this invention,

Figure 5 a diagrammatic cross-sectional view of a fifth embodiment of this invention, and

Figure 6 a diagrammatic cross-sectional view of a sixth embodiment of this invention.

In the figures, advantages and features of the invention are characterized with these reference symbols, identified in each case, according to embodiments of the invention, whereby components or features with the same function or a function with the same effect are characterized with identical reference symbols.

In the figures, the features according to the invention are not depicted to scale in order to be able to actually depict the function of the individual features. Also, the ratios of the individual components are in part disproportionate, which can be attributed in particular to structures 2 and pores 5 that are depicted greatly enlarged. The structures 2, which with this invention are embossed or are used to emboss corresponding nanostructures onto workpieces, are in the nanometer and/or micrometer range, while the order of magnitude of the machine components is in the centimeter range.

The dimensions of the individual structures 2 of an embossing surface 2o of a structural die 1 preferably are in the micrometer and/or nanometer range. The dimensions of the individual structures 2 are less than 1,000 μm, preferably less than 10 μm, more preferably less than 100 nm, even more preferably less than 10 nm, and with utmost preference less than 1 nm.

In the embodiments shown in Figures 1 to 4, structural dies 1, 1', 1", 1''' that are brought into contact by linear movement with a target surface 4o of a substrate 4 are shown.

In the embodiments shown in Figures 5 and 6, structural dies 1^{IV}, 1^{V} are shown, which are continuously brought into contact by rotational movement around an axis of rotation of the structural die 1 with a target surface 4o of a substrate 4 by rolling along the target surface 4o.

Figure 1 shows a first embodiment, according to the invention, of the structural die 1, preferably produced from PFPE, with structures 2, to whose embossing surface 2o an embossing material 3 adheres. The embossing material 3 has a first surface 3o that faces the embossing surface 2o and a second side 3u that faces a target surface 4o of the substrate 4. The embossing material 3 is applied beforehand in a coating step, not shown, by immersing the structures 2 in a reservoir of in particular liquid embossing material 3 on the embossing surface 20.

Figure 2 shows a second embodiment, according to the invention, of the structural die 1' that is preferably produced from PFPE and that is distinguished from the structural die 1 by its pores 5. The pores 5 have an open porosity, so that the fluid transport of the embossing material 3 from a

back side 1o of the die 1' that faces away from the embossing surface 2o to the embossing surface 2o of the structures 2 can be carried out.

Figure 3 shows a third embodiment, according to the invention, of a structural die 1" that is preferably produced from PFPE and that is distinguished from the die 1' by a foil 8 that was attached on its back side 1o. The foil 8 has projections 10, which separate cavities 9 from one another. The cavities 9 are used for receiving the embossing material 3, which can diffuse through the die 1" and thus can go to the embossing surface 2o of the structures 2. The projections 10 can be in particular columns or dies (pillars) or drawn-out walls that run across the entire width. The projections 10 are used predominantly for supporting the die 1". The foil 8 has a thickness of between 100 and 2,000 µm. The height of the cavities 9 or the height of the projections 10 is between 100 µm and 500 µm. The foil 8 is preferably connected to a side periphery 11 of the foil 8, and the structural die 1 is connected to the die 1". In this connection, it can be a bonding, a welding or a type of connection that is preferably permanent in some other way.

Figure 4 shows a fourth embodiment, according to the invention, of a die 1''', which is mounted on a carrier 14, which is preferably also porous. The carrier 14 preferably consists of a ceramic or a metal or a high-strength and hard polymer. The die 1''' and the carrier 14 are surrounded by a shield 12. The embossing material 3 can be stored in a cavity 15 via the carrier 14. The diffusion of the molecular component 3 by the support plate 14 and the die 1''' is accordingly carried out as in the other above-mentioned embodiments. The carrier 14 can be connected to the die 1''' by the material of the die 1''' being moved into the porous structure of the carrier 14 or is squeezed through during the production process of the

connection. Since the material of the die 1''' is preferably very soft, the die 1''' can be produced, for example, on the carrier 14. During the production process, the highly viscous but always still liquid embossing material, from which the die 1''' is produced, can already partially penetrate into the pores of the carrier 14 and thus produces a connection between two elements. After the hardening of the embossing material of the die 1", the latter is tightly connected to the die 14. According to the invention, the carrier 14 and the die 1''' need not be connected to one another, however, but rather can also be pressed on one another or at least held together only by the shield 12 or any other device.

Figure 5 shows a fifth embodiment, according to the invention, of a structural die 1^{IV} in the shape of a roller 1 that is preferably produced from PFPE and that can be viewed as a round die. A dispenser 6 provides for an in particular continuous and long-lasting wetting of the embossing surface 2o of the structures 2 with the embossing material 3. The transfer of the embossing material 3 onto the target surface 4o is carried out by a corresponding relative movement of a substrate 4 to the structural die 1^{IV}. In the most preferred embodiment, the structural die 1^{IV} is mounted to rotate around a rotational axis 7, while the substrate 4 is moved in a translatory or tangential manner to the roller at a speed v.

Figure 6 shows a sixth embodiment, according to the invention, of a structural die 1^{IV} in the form of a roller 1 that is preferably produced from PFPE and that can be viewed as a round die. The structural die 1^{V} is produced as a hollow shaft. A cavity in the interior of the hollow shaft is used as a reservoir for the embossing material 3. The structural die 1^{V} has a porous microstructure that consists of pores 5 and that makes possible the passage

of the embossing material 3 from the cavity to the surface 2o of the structures 2. The transfer of the molecular component 3 onto the target surface 4 is carried out by a movement of a substrate 4 relative to the roller corresponding to the fifth embodiment.

Method for Microcontact Embossing

List of Reference Symbols

1, 1', 1", 1''',	Structural die
1^{IV}, 1^{V}	Structural die
1o	Back side
2	Structures
2o	Embossing surface
3	Embossing material
3o	First side
3u	Second side
4	Substrate
4o	Target surface
5	Pores
6	Dispenser
7	Axis of rotation
8	Foil
9	Cavities
10	Projections
11	Side periphery
12	Shield
14	Carrier
15	Cavity
V	Speed

Method for Microcontact Embossing

Claims

1. Method for microcontact embossing of a structure by transfer of an embossing material (3) onto a target surface (4o) of a substrate (4) by means of an embossing surface (2o) of a structural die (1), characterized in that the embossing material (3) consists at least predominantly of silane or at least predominantly of at least one silane derivative or is a molecular component that consists at least predominantly of organic molecules and in that the structural die (1) is a soft die.

2. Method according to Claim 1, in which the molecular component has at least one or more of the structures mentioned below:

- Enzymes,
- Alkaloids,
- Lipids,
- Hormones,
- Pheromones,
- Vitamins,
- Carbohydrates,
- Peptides,
- Nucleic acids,
- DNA or DNA strands,
- Cells,
- Proteins or peptides,
- Alkanes, alkenes, alkines, aromatic compounds
- Graphene.

3. Method according to one of the preceding claims, in which the structural die (1) has an elasticity/a modulus of elasticity of 10^{-3} MPa and 100 MPa, preferably between 10^{-2} MPa and 80 MPa, more preferably between 10^{-1} MPa and 60 MPa, and most preferably between 3 MPa and 40 MPa.

4. Method according to one of the preceding claims, in which the structural die (1) is acid-resistant and/or base-resistant.

5. Method according to one of the preceding claims, in which the structural die (1) consists at least predominantly, preferably completely, of an inert material.

6. Method according to one of the preceding claims, in which the structural die (1) is at least partially, preferably predominantly, porous.

7. Method according to one of the preceding claims, in which the structural die (1) is formed from a polymer, in particular PFPE or PDMS.