Nanostructure Die, Embossing Roll, Device and Method for Continuous Embossing of Nanostructures

Specification

This invention relates to a nanostructure die for embossing of an embossing roll ~~as claimed in Claim 1~~, an embossing roll for continuous embossing of nanostructures ~~as claimed in Claim 4~~, a device for producing an embossing roll for continuous embossing of nanostructures ~~as claimed in Claim 7~~, a method for producing a nanostructure die for producing an embossing roll ~~as claimed in Claim 11~~, and a method for producing an embossing roll for continuous embossing of nanostructures ~~as claimed in Claim 14~~. Moreover this invention relates to a method for producing an embossing substrate which has nanostructures ~~as claimed in Claim 18~~.

In the development of mass production technologies of nanostructured surfaces and semiconductor structures for large area applications such as for example foils or films, there is a demand for functioning roll-to-roll machines which are able to emboss continuous nanostructured and/or semiconductor structures via rolling onto a track or a long workpiece. Major problems prevail here, especially in an application for imprint lithography; this has not been satisfactorily resolved to date.

In particular, one problem is to produce continuous patterns in the submicron or nanometer range. It can be easily imagined that as the embossing structures become smaller and smaller the technical problems increase in the implementation of continuous application to an above average degree.

Embodiments ~~The object~~ of this invention ~~is therefore to~~ devise a nanostructure die and an embossing roll and method and device for producing them, with which continuous embossing of nanostructures is

possible even for very small dimensions of the nanostructures, especially relative to the size or to the diameter of the embossing roll, and reliable and reproducible results can be achieved. The diameters of current embossing rolls are known to one skilled in the art. The embodiment as claimed in the invention is in any case suitable for any diameter.

According to a first aspect, there is provided the use of a body of revolution of an embossing roll in the step-and-repeat process for production of a nanostructure die with a concavely curved nanostructured die surface for seamless embossing of at least one peripheral ring of a jacket surface, wherein the nanostructure die has a die carrier to which a die form which encompasses the die surface is connected.

According to a second aspect, there is provided a method for producing a nanostructure die for producing an embossing roll for continuous embossing of nanostructures with the following steps, especially the following sequence:

- fixing of a curved or curvable die negative of the nanostructure die on a peripheral section of one jacket surface of a body of revolution,
- application of a moldable die form material to the curved die negative,
- molding of the die form material on a die carrier for forming a concavely curved nanostructured die surface,
- curing of the die form material.

~~This object is achieved with the features of Claims 1, 4, 7, 11, 14 and 18. Advantageous developments of the invention are given in the dependent claims.~~ All combinations of at least two of the features given in the specification, the claims and/or the figures also fall within the framework of the invention. At the given value ranges values which lie within the indicated limits are also to be considered disclosed and claimed in any combination.

Embodiments of t~~T~~he invention are~~is~~ based on the idea of applying an embossing structure which is to be applied to the embossing roll in the step- and-repeat process such that there is seamless embossing on the entire periphery. To do this, ~~as claimed in the invention~~ a novel nanostructure die as per embodiments of the invention is disclosed which is suitable for a step-and-repeat process in order to apply a repeating structure on the periphery of the embossing roll.

Embodiments of ~~It is also conceivable as claimed in~~ the invention ~~to~~ apply the structure along one axis of rotation of a body of revolution in the step-and-repeat process. It is of special importance ~~as claimed~~ in embodiments of the invention to produce a seamless microstructure or nanostructure with embossing in several steps so that the embossing roll in the later unwinding process can be transferred to the workpiece (producing an embossing substrate, also embossing product) more or less endlessly or continuously, therefore by a plurality of complete revolutions. The highly symmetrical and translational repetitions of the patterns which can be achieved with the step-and-repeat process makes it possible to generate materials with unique surface properties, especially with periodically repeating

structures. Use is especially advantageous in the field of optics, for example in the imprinting of glass plates. Symmetry in optics is of very great importance, especially when the desired optical effects can be achieved with greatest precision by highly symmetrical structures. Seamless means that within the tolerances of the step-and-repeat process on the entire periphery homogenous structures are embossed, especially also on the transition of the last embossing step to the first embossing step of peripheral embossing of the embossing roll.

Therefore an embodiment of the~~independent~~ invention is a nanostructure die with a for example concavely curved nanostructured die surface for seamless embossing of at least one peripheral ring of a jacket surface of an embossing roll in the step-and-repeat process. The die surface of the nanostructure die is thus matched to the jacket surface of the embossing roll so that the entire jacket surface of an embossing roll can be embossed with a single nanostructure die. The simultaneous use of several nanostructure dies in the embossing of an embossing roll is likewise conceivable as per embodiments of~~claimed in~~ the invention.

To the extent the nanostructure die has a die carrier to which a die form which encompasses the die surface is connected, especially permanently, the handling of the nanostructure die in a corresponding device for embossing of the embossing roll is simplified.

It is especially advantageous if the die form is produced directly by the embossing roll which is to be embossed. In this way the curvature of the nanostructure die or of the die surface of the nanostructure die corresponds exactly to the embossing roll which is to be embossed.

According to one advantageous embodiment of the invention, the die carrier is transparent to electromagnetic waves, especially UV light, in order to be able to provide curing of the die form and/or of the embossing layer of the embossing roll, which layer is to be embossed.

To the extent a radiation source for electromagnetic waves, especially a UV source, is located within the embossing roll, especially in the form of a hollow cylinder, there is preferably a shielding means for the electromagnetic waves in regions of the embossing roll which are not to be exposed, especially on its inner periphery. This is preferably a UV-opaque protective jacket which protects all those sites which are not to be illuminated and is interrupted only on those regions through which the UV light is intended to pass in order to cure the embossing layer which can be cured by UV.

Advantageously a radian measure of the die surface of the nanostructure die as per embodiments of~~claimed in~~ the invention in one unwinding direction on the embossing roll with reference to a corresponding circular periphery of the embossing layer to be embossed is an integral part so that in complete embossing of the circular periphery of the embossing layer in the unwinding direction of the embossing roll seamless embossing takes place. To the extent there is an overlapping section in the individual embossing steps as per embodiments of~~claimed in~~ the invention, the radian measure can be expanded by the overlapping section.

In addition it is provided as per embodiments of~~claimed in~~ the invention that the die can be dynamically deformed by deformation means, especially by external influence, in the micrometer and/or nanometer ranges, especially can be stretched and/or compressed.

In one embodiment of the deformation means this is achieved by the thermal expansion of the die by heating and/or cooling. In another embodiment, piezomaterials are used. For one skilled in the art in the field it is clear that the stretching of the die can be achieved in any manner, as long as it is ensured that the embossing structures pass seamlessly into one another when the surface is closed. To do this, there can be measurement means for measuring the ratios of the die surface

relative to the circular periphery of the embossing roll, especially for detection during the working (embossing). Alternatively, the degree of deformation can be fixed by calibration, especially by an embossing of the periphery. It is also conceivable as per embodiments ofclaimed in the invention to measure the periphery of the embossing roll with and/or without the embossing layer on the one hand and the dimension of the die surface on the other and then to determine the deformation, especially by computation. As per embodiments ofclaimed in the invention especially scanning force microscopes and/or optical microscopes and/or scanning electron microscopes are suitable as measurement methods.

An embodiment of theindependent invention is also the embossing roll which has been produced especially with the nanostructure die as per embodiments ofclaimed in the invention for continuous embossing of nanostructures with an embossing layer which has been applied to a body of revolution with a jacket surface with at least one peripheral ring which has been embossed in the step-and-repeat process and formed seamlessly in the peripheral direction. Periodically repeating structures can be applied to a workpiece with the embossing roll.

The embossing roll can be advantageously produced by the jacket surface being embossed by the nanostructure die as per embodiments ofclaimed in the invention.

It is especially advantageous if the body of revolution is made as a cylinder, especially a circular cylinder. Thus the embossing roll can be advantageously used both in the production of the embossing roll and also in the functional use of the embossing roll in the continuous embossing of nanostructures (imprints).

An embodiment of theindependent invention is moreover a device for producing an embossing roll as per embodiments ofclaimed in the invention for continuous embossing of nanostructures. It has an embossing roll receiver for accommodation and controllable rotation of a body of revolution of the embossing roll around an

embossing roll axis in a working space. The control takes place especially via a central control device. Furthermore the device as per embodiments ofclaimed in the invention has a die receiver for accommodation and controllable movement of a nanostructure die especially as per embodiments ofclaimed in the invention relative to one jacket surface of the embossing roll. The control likewise takes place by the central control device, by controlling the embossing roll receiver and the die receiver at least one peripheral ring being producible which has been embossed in the step-and-repeat process and which is made seamless at least in the peripheral direction of the jacket surface. In one advantageous embodiment of the device the working space is formed by a vacuum chamber and can be exposed to a vacuum so that during the production of the embossing roll an atmosphere which is suitable for production can be established.

According to another embodiment of the invention it is advantageously provided that there are means for applying an embossing layer which forms the jacket surface to a body of revolution of the embossing roll. This embodiment provides for further integration.

In another advantageous embodiment of the invention, it is provided that the device has curing means for curing of the embossed peripheral ring especially in sections, preferably with sections which correspond especially to a die surface of the nanostructure die and which correspond to the step-and-repeat process.

Furthermore an embodiment of theindependent invention relates to a method for producing a nanostructure die for producing an embossing roll for continuous embossing of nanostructures with the following steps, especially the following sequence:

- fixing of a curved or curvable die negative of the nanostructure die on a peripheral section of one jacket surface of a body of revolution,

- application of a moldable die form material to the curved die negative,
- molding of the die form material on a die carrier for forming a concavely curved nanostructured die surface,
- curing of the die form material.

According to one advantageous embodiment of the invention it is provided that the peripheral section extends over less than half, especially less than 1/3, preferably less than 1/4 of the periphery of the jacket surface. The embossing force is applied more uniformly by these measures.

To the extent the body of revolution is a body of revolution of the embossing roll, the curvature of the die surface corresponds exactly to the shape of the embossing roll during embossing, especially when the thickness of the die negative corresponds roughly to the thickness of the embossing layer on the embossing roll.

Another embodiment~~According to another independent aspect~~ of this invention~~, it~~ relates to a method for producing an embossing roll for continuous embossing of nanostructures with the following steps, especially the following sequence:

- receiving a body of revolution with an embossing layer which has a jacket surface onto an embossing roll receiver which is located in a working space,
- embossing of a peripheral ring which is made seamless in the peripheral direction of the jacket surface by means of a nanostructure die held on a die receiver in the step-and-repeat process.

The arrangement of the peripheral ring agrees exactly with the axis of rotation of the body of revolution of the embossing roll by embossing being done by rotation of the body of revolution in several especially sequentially running stamping steps.

According to another advantageous embodiment of this invention it is provided that the stamping steps are carried out for alignment partially overlapping on the structure which has been embossed beforehand. In this way an alignment of the nanostructure die on previously embossed and cured structures as per embodiments of~~claimed in~~ the invention is conceivable so that high precision alignment takes place using the structures which have been embossed by the different stamping steps.

Because there are several stamping steps parallel to the axis of rotation in each rotation position the embossing roll is embossed to completion after a single complete rotation around the axis of rotation (therefore roughly 360 degrees, optionally with slight overlapping).

Features disclosed for the hardware should also be considered as disclosed as method features and vice versa.

Other advantages, features and details of the invention are illustrated by the following description of preferred exemplary embodiments and using the drawings; the drawings are schematic.

Figure 1a shows a first embodiment of the device as claimed in the invention for producing an embossing roll for continuous embossing of nanostructures,

Figure 1b shows a second embodiment of the device as claimed in the invention for producing an embossing roll for continuous embossing of nanostructures,

Figures 2a to 2f show one embodiment of a method as claimed in the invention for producing a nanostructure die for producing an embossing roll for continuous embossing of nanostructures,

Figures 3a to 3g show one embodiment of a method as claimed in the invention for producing an embossing roll for continuous embossing of nanostructures,

~~amended~~ Claims

1. Use of a body of revolution (5) of an embossing roll (16) in the step-and-repeat process for production of a nanostructure die (1) with a concavely curved nanostructured die surface (7f) for seamless embossing of at least one peripheral ring (15, 15') of a jacket surface (13o), wherein the nanostructure die (1) has a die carrier (11) to which a die form (7) which encompasses the die surface (7f) is connected.

2. A method for producing a nanostructure die (1) for producing an embossing roll (16) for continuous embossing of nanostructures with the following steps, especially the following sequence:

- fixing of a curved or curvable die negative (9) of the nanostructure die (1) on a peripheral section of one jacket surface (5o) of a body of revolution (5),
- application of a moldable die form material (10) to the curved die negative (9),
- molding of the die form material (10) on a die carrier (11) for forming a concavely curved nanostructured die surface (7f),
- curing of the die form material (10).

3. The method as claimed in Claim 2, in which the peripheral section extends over less than half, especially less than one third, preferably less than one fourth, of the periphery of the jacket surface (5o).

4. The method as claimed in Claim 2 or 3, in which the embossing roll (16) is used as the body of revolution (5)