# Process and Device for Embossing

This invention relates to a process for embossing a structure in an embossing material applied on a substrate as well as a corresponding device.

In many branches of industry, but with the semiconductor industry leading the way, embossing (imprinting) technologies are always important in order to produce microstructures and/or nanostructures at low expense, low costs and short processing times.

Known imprinting technologies are processes in which a die is pressed by force into an embossing material in order to produce a negative of the die. The materials of the embossing material used in this case can be hardened after the embossing process by different chemical and/or physical processes, so that the embossing material correspondingly hardens and is dimensionally stable after the die is removed.

The hardening is done by, for example, irradiation with UV light, by heating by means of heating elements, by electrical and/or magnetic fields, by chemical reaction with a reagent, etc.

During thermal hardening, the heating and cooling are carried out, especially repeatedly, in a chamber, so that high costs because of stringent energy and time requirements result.

Embodiments of this invention disclose a process and a device with which a quick, efficient and economical embossing of an especially thermally-hardenable embossing material is made possible.

According to an aspect, there is provided a process for embossing a structure in an embossing material that is applied on a substrate, comprised of the steps of: embossing the embossing material by an embossing die, and hardening the embossing material, by irradiating with microwaves three or more of the following: the substrate, the embossing die, a heating layer comprised of a molecular dipolar compound arranged between the substrate and the embossing material, and a heating layer comprised of a molecular dipolar compound arranged between the embossing die and the embossing material.

Also, all combinations of at least two of the features indicated in the description, the claims and/or the figures 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.

Embodiments of the invention are based on the idea of irradiating the substrate holding the embossing material and/or a die and/or a heating layer arranged between the substrate and the embossing material and/or between the die and the embossing material with microwaves to harden the especially thermally-hardenable embossing material. The substrate and/or the die and/or the heating layers in this case are selected according to embodiments of the invention in such a way that the latter can be heated by microwaves. By the irradiation with microwaves, a targeted (indirect) heating of the especially thermally–hardenable embossing material is provided, so that efficient control of the hardening process and the specified heating temperatures and/or heating processes is made possible. In particular, it is conceivable according to embodiments of the invention to provide temperature sensors on the substrate and/or the die and/or the heating layer, preferably on the side facing away from the embossing material, in order to make possible the control of the microwave irradiation based on the actual measured temperature.

Thermal hardenability is defined as the capacity of materials, after a heat treatment, to occupy a dimensionally stable state. These primarily, but not exclusively, include the materials of the material groups thermoplasts and duroplasts.

As additional embodiments of this invention, in particular the separation/demolding of the embossing die from the hardened embossing material via separating means is provided. This is carried out in particular in a separate process step and/or a preferably physically separated device module.

Hereinafter, substrate means any element on which an embossing material is applied. The substrate can be a die that is covered with the embossing material.

In an advantageous embodiment of the invention, it is provided that the microwaves that are used for irradiation are electromagnetic waves with a frequency of between 0.01 GHz and 100 GHz, in particular between 0.1 GHz and 50 GHz, preferably between 1 GHz and 10 GHz, and even more preferably between 2 GHz and 5 GHz. Most preferred is a frequency of 2.45 GHz, so that in particular existing microwave devices can be used for the irradiation.

In further embodiments of the invention, it is provided that a molecular dipolar compound, in particular deionized water, is used as a heating layer. As a molecular dipolar compound, solids and/or liquids, in particular organic substances, are suitable. The molecular dipolar compounds are applied on the substrate, in particular by condensation of moisture, present in the atmosphere, on the surface of the substrate. As an alternative, the application of a liquid and/or solid film on the embossing substrate can be carried out by a suitable coating process. In particular, the use of a spin-coating unit is provided, on which the thickness of the liquid and/or solid film can be reduced, preferably by a centrifuging process, to a few monolayers. In particular, a layer thickness for the molecular dipolar compound of less than 10 monolayers, preferably less than 5 monolayers, and even more preferably less than 3 monolayers, is provided. According to

embodiments of the invention, the thickness of the molecular dipolar compound is in particular less than 1 mm, preferably less than 100 μm, more preferably less than 10 μm, most preferably less than 1 μm, and with utmost preference less than 0.1 μm.

By the substrate having a molar heat capacity of between 0.001 J/gK and 100 J/gK, more preferably between 0.01 J/gK and 10 J/gK, even more preferably between 0.1 J/gK and 1 J/gK, and most preferably between 0.7 and 0.8 J/gK, the hardening can be controlled more efficiently without resulting in local overheating. Heat capacities at constant pressure or constant volume can be determined with corresponding calorimeters.

By selecting the proper material, the heat conduction of the substrate is set as high as possible in order to emit the heat into the environment as quickly as possible and thus into the embossing material. The substrate according to embodiments of the invention preferably has a heat conductivity of between 0.10 W/(m*K) and 3,000 W/(m*K), preferably between 1 W/(m*K) and 1,000 W/(m*K), more preferably between 10 W/(m*K) and 200 W/(m*K), and with utmost preference between 100 W/(m*K) and 155 W/(m*K).

In another embodiment, the use of organic films as a heating layer for hardening the embossing material by means of microwave irradiation is disclosed. In particular, organic films at least predominantly consisting of bipolar molecules, preferably with a high level of adhesive action on the substrate and/or a lower level of adhesive action on the embossing material are suitable. For this purpose, the embossing material can be easily removed from the substrate after hardening. The high level of adhesion to the substrate ensures that the heating layer does not separate from the substrate during heat loading by microwave irradiation.

In another embodiment, a doped substrate for embossing a structure in an embossing material applied on the substrate, in particular according to the previously-described process, is disclosed. The doping is selected in such a way that after doping, the substrate is better heated by microwaves of a specific frequency range, i.e., it responds better to the microwaves. All standard doping elements for the corresponding substrates are known to one skilled in the art. By way of example, the doping with phosphorus (P), boron (B), arsenic (As) and antimony (Sb) in silicon can be disclosed.

Embodiments of the device are further developed in which the microwave irradiating means are oriented in such a way that the action of the microwaves is oriented perpendicular to the substrate surface, i.e., the Poynting vector of the microwave rays is normal to the substrate surface.

In a further embodiment of the invention, it is advantageously provided that the substrate has a thickness of between 10,000 μm and 0.1 μm, preferably between 1,000 μm and 1 μm, and more preferably between 100 μm and 10 μm, and/or it has a diameter of more than 1". Preferred diameters in the semiconductor industry are 1'', 2", 3", 4", 5", 6", 8", 12" or 18". Embodiments of the invention, however, are not limited to a substrate with a standardized diameter. Because of the small thickness of the substrate, a very quick heating of the substrate with low energy consumption is possible. Because of the comparatively large diameters, a large-surface embossing material can be embossed with a single sequence of the process.

To the extent that process features are described, the latter are also to be regarded as disclosed as device features and vice versa.