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Fully automated hot embossing processes utilizing high resolution working stamps

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ABSTRACT

Nanoimprint lithography (NIL) is a fast replication technology for structures with sizes ranging from micrometer down to few nanometers range. This paper describes the technology for imprinting of polymer substrates as well as spin-on polymers by using soft working stamp materials. A fully automated hot embossing system, the EVG®750 was built to use this rapid replication processes. By utilizing soft working stamps, we demonstrate the possibility to replicate, in fully automated mode, both high-aspect ratio features in thermoplastic materials as needed for microfluidic lab-on-chip applications as well as high resolution features down to 50 nm in polymer that can be used as templates for pattern transfer in the fabrication of plasmonic substrates for bio-sensing applications.

1. Introduction

Hot embossing is a patterning technique for thermoplastic polymer sheets and spin-on polymers on substrates. It enables the creation of two-dimensional and three-dimensional structures by applying elevated temperatures and high contact forces. The similarities in regards to process parameters and equipment specifications between wafer bonding and hot embossing have led to the modifications of wafer bonder systems used for thermo-compression bonding processes to accommodate embossing processes some years back [1]. The low cost fabrication of disposable, polymer based devices needed for emerging point-of-care diagnostic or bio-sensing devices can be realized by hot embossing processes at low cost. Hot embossing processes are generally used to address different applications ranging from polymer based lab-on-chip systems, where imprinting is performed on thick polymers sheets, to the fabrication of sub 100 nm features for bio-sensing or data recording applications, which requires imprinting into thin (less than 200 nm) spin-on layers. The use of microfluidic devices for medical or environmental diagnostics requires the fabrication of a large number of devices that is beyond the replication throughput of the exiting R&D embossing systems. The injection molding technologies are not well adapted to cover this transition from the R&D to prototyping series because of the costly initial investment in molds and processing equipment. Consequently, the development of commercial applications based on hot embossing processes requires fabrication systems and processes with throughputs that are beyond the existing R&D tools. The need for fully automated processes implies an automated de-embossing process of stamp and imprinted substrate. While a range of micro fluidic devices are still fabricated by using Si wafers, there is a demand for cheap, disposable and thus polymer based devices [2,4]. A cheap manufacturing method is required to fabricate those devices, which also demands an inexpensive fabrication method for stamps. Soft working stamps provide a cost effective alternative to Si or Ni based masters since and can be replicated many times from those masters and the original masters are not used for imprinting directly. The soft stamp materials have been used for UV-based nanoimprint lithography processes where no high temperature and force is required to transfer the structures into the polymer [3]. However, the use of such working stamps for hot embossing processes has not been reported so far and is described in the current work. The use of the soft working stamps materials allow a reliable and residue-free separation of stamp and imprinted substrate after imprinting, which is a key issue for automated process runs by using an anti-adhesive monolayer on the stamp surface [3,5]. Another important aspect is the use of compliant layers that ensure imprint uniformity over large areas. This paper demonstrates the realization of a fully automated hot embossing process for spin-on polymers as well as thick (0.5–3 mm) polymer substrates, which includes handling as well as

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automatic embossing and de-embossing using soft stamps materials. The experiments were performed on the first fully automated hot embossing system initially developed for hard disc double side patterning using Ni-stamps [4,6].

2. Hot embossing equipment

A fully automated hot embossing system, the EVG® 750, was developed and built. It supports four different processes for 100 and 150 mm diameter substrates. All of them are utilizing soft working stamps. The simplest process is the first imprint process in polymer, which defines structures in a polymeric substrate. A similar process is performed for structuring of spin-on polymer layers deposited on a Si wafer, representing process number two. The third process, called aligned imprint in spin-on polymers is using a Si wafer with pre-defined alignment keys and a working stamp containing the corresponding alignment keys in the working stamp material. The substrate and the stamp are optically aligned, followed by the imprinting process. The fourth process is a double side aligned imprinting process in a polymer substrate. It is intended for the replication of multilevel polymer structures integrating micro fluidic circuitry as well as micro-optics elements for optofluidic applications.

The hardware of the EVG® 750 consists of the following main modules: (1) an alignment module for the aligned imprint processes, (2) a hot embossing module for performing hot embossing processes and (3) a cooling station for cooling the imprint tooling down to room temperature (Fig. 1).

The equipment supports fully automated cassette-to cassette handling of Si substrates, polymer sheets and working stamps.

First tests have shown an alignment accuracy of better than 10 μm. The design of the used alignment keys were similar to those used for mask alignment systems with a size of about 50 μm. The alignment results are in-line with the requirements for micro fluidic devices. More details concerning alignment results will be published later.

In contrary to established hot embossing applications, the process we are reporting here employs soft working stamp materials which exhibit manifold benefits over hard stamp materials like Si or Ni: (1) soft working stamps can be fabricated at low cost from expensive e-beam written masters, (2) the use of soft working stamps does not require additional compliant layers as they already exhibit this trait and (3) these stamps are transparent and therefore fully compatible with optical live alignment to a structured Si substrate or to a second working stamp for double side imprinting.

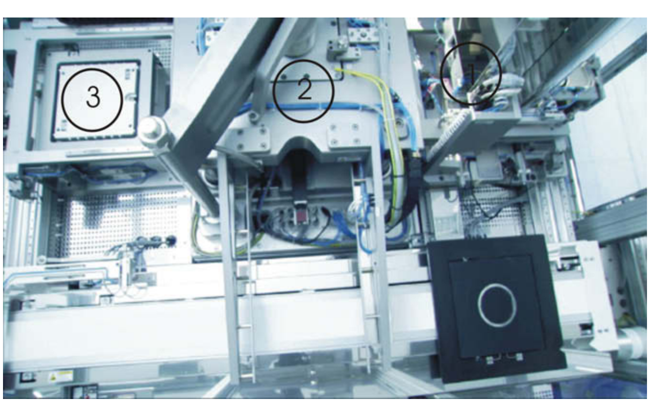

Fig. 1. Close-up of the main modules of the EVG750; (1) alignment module; (2) imprinting module; and (3) cooling module; belt conveyer is shown at picture bottom side.

2.1. Fully automated de-embossing of stamp and imprinted substrate

A method for automated de-embossing that uses an "air knife" to separate the Si-stamp that is mechanically fixed to a top chuck has been proposed by a different group [5,7]. While this method is successful in separating the stamp and the imprinted substrate inside the hot embossing module, a full automation including substrate and stamp handling might be difficult to realize with the proposed method. First of all the Si-stamp is permanently fixed on the top chuck, which makes an optical alignment very difficult. In that case the alignment would have to be performed in the hot embossing chamber by applying IR-alignment as the substrate and the Si-stamp are non-transparent. Secondly, the de-embossing relies on the high adhesion of the imprinted Si to a compliant layer (poly-dimethyl-siloxane) so that another de-embossing process step would have to be implemented for the separation of the substrate from the PDMS layer.

In the current work the de-embossing process was realized in the following way. The backplane of the working stamp is fixed by vacuum on its respective top chuck surface and the Si substrate with spin-on layer is vacuum fixed on the bottom counterpart chuck surface. After the performed hot embossing process the Si substrate with imprinted spin-on layer is vacuum released from the bottom chuck and thus the whole stack is transferred to the top chuck during the opening of the hot embossing module. A de-embossing arm is moving into the imprinting module in between top and bottom chuck and is separating the Si substrate by vacuum fixation from the working stamp in a parallel way. The de-embossing arm moves out of the imprinted press and the substrate is transferred to a robot end-effector. Substrates are unloaded to the receive cassette. Imprinted polymer substrates are separated from the working in a similar way. The exception to the described de-embossing process of spin-on polymer substrates is that polymer substrates are transferred via a small pin through a center hole of the working stamp backplane to the top chuck during the hot embossing chamber opening. That way the de-embossing arm is picking up either the spin-on imprinted substrate or the polymer substrate always from the top chuck.

3. Imprinting processes and results

3.1. Preparation of working stamps

Soft working stamps were fabricated from Ni masters or directly from resist masters after optical lithography. In Fig. 2 the ba-

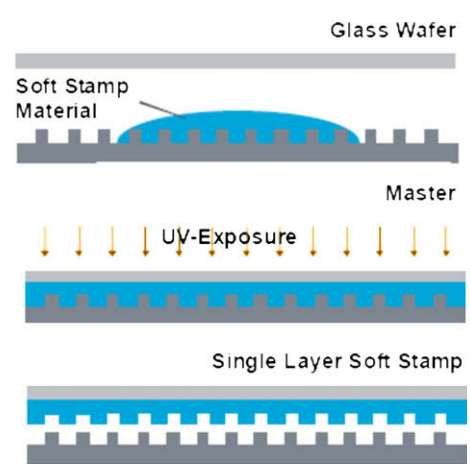

Fig. 2. Basic process of soft working stamp fabrication.