

# Industrial Applications Requiring Low and High Resolution Features Realized by Hot Embossing

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**ABSTRACT:** As the fields of microfluidics and biosensors mature, high volume Hot Embossing (HE) is emerging as an important, enabling technology to make these products more cost-effective. The challenges in bringing HE applications into volume production are several. These include the requirements to uniformly print both fine features sizes (sub-100 nm) into spun-on polymers as well as gross feature sizes into bulk substrates with a stamp that allows for a facile de-embossing step. Also, the total thickness variation (TTV) associated with the substrates to be imprinted requires the use of a stamp material that can comply with the imprinted substrate's surface to allow for a full-field imprint. Thus, EV Group Inc. (EVG) has, in cooperation with our NILCOM™ partners, identified a novel set of UV-curable, polymeric materials and stamp fabrication processes that allow for manufacturing of said soft-stamps and for full-field imprinting solutions suitable for these high volume HE environments. This new “soft” or “working” stamp technology has recently been deployed on the EVG 750™, a fully automated hot embossing system.

*Keywords:* Hot-embossing, soft stamps, microfluidics, full-field imprinting, working stamps.

## 1. INTRODUCTION

The use of hot embossing as a cost-effective patterning technique is quickly making its way into mainstream fabrication of microfluidic and biosensing devices. Silicon wafers currently make up the bulk of the fabrication media for microfluidic devices, however, there is a growing demand for inexpensive and disposable polymer-based devices [1]. Presently, the vast majority of hot embossing systems in the field have been adapted from wafer bonding systems [2]. These systems are typically manual or semi-automated machines that require user intervention while loading and unloading of both substrates and stamps into the equipment for the imprinting process. This methodology is not conducive to the high volume manufacturing environment that will be required by the emerging chemical sensor, biosensor, and point-of-care diagnostic markets that the aforementioned polymer-based devices are targeting. Also, the current hot embossing systems usually employ a “hard” stamp approach for embossing. The hard stamps are usually made of materials such as silicon or nickel. Both of these “hard” stamp approaches have their benefits and drawbacks. Silicon hard stamps can be manufactured relatively inexpensively. However, they also are quite fragile and do not stand-up well to the high force environments required by hot embossing. Additionally, they require an anti-stiction coating that adds expense to the process and needs to be reapplied from time to time – adding additional costs to the overall process.

A nickel stamp, on the other hand, is well suited for hot embossing's high force environment, but it also has drawbacks when it comes to cost. Firstly, the nickel stamp is formed from a silicon master in a time-consuming LIGA process. Also, all hard stamp materials, due to their rigidity, can have issues conforming to the entire substrate surface due to total thickness variations (TTV) in both the stamp and imprinted substrate. This issue will be compounded as

manufacturers move to larger substrate sizes. Finally, most hard stamp materials do not allow for direct, optical alignment techniques, a major limit to their utility. Therefore, what is needed for high volume HE applications is a new stamp material that provides: inherently low surface energy (e.g. no need for an anti-stiction layer), to facilitate automated de-embossing; robustness, to allow for multiple imprints; compliance, to allow for single step, full-field embossing over a large area and optical transparency, to allow for direct alignment with the embossing substrate. In this paper, we will present a novel, polymeric soft-stamp approach specifically targeted for high volume hot-embossing applications that exhibits all of these characteristics.

The fabrication of these “soft” or “working” stamps can be achieved from a “hard” stamp usually made from materials such as nickel, quartz or silicon. Thus the expensive master does not need to be exposed to the HE environment where it can be damaged. Originally developed for UV nanoimprint lithography applications, these newly identified materials have proven effective for HE at both micrometer feature sizes all the way down to 50 nm – full field. They can be fabricated using standard mask aligner technology. Also, they have very low surface energies which allow for facile, residual-free, automated de-embossing and repeated use. The soft-stamps are a polymeric material that is compliant and allows for full-field embossing. These working stamps are also optically transparent enabling direct optical alignment with the substrate to be embossed as well as another soft stamp for double-sided imprinting. These materials, and the processes associated with their fabrication into working/soft stamps, should allow for a superior cost-of-ownership benefit and facilitate the movement of HE into industrial applications.

## **II. HOT EMBOSSING EQUIPMENT:**

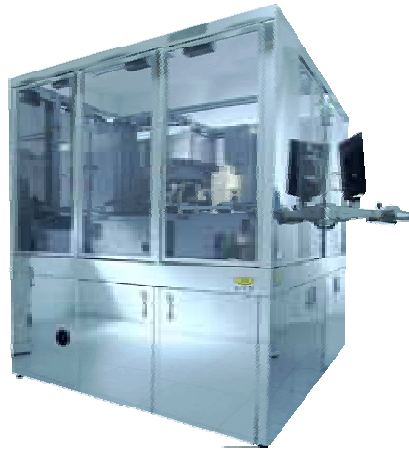
The soft stamp results related in this paper were performed on the EVG 750™ Hot Embossing system (Fig. 1). The system was specifically designed to meet the needs of emerging high volume hot embossing applications. The tool can handle a variety of stamp materials – both hard and soft, and offers cassette-to-cassette operations for a diverse set of substrates as well. Thus, all embossing processes are fully automated. These processes include: loading of substrate and stamp from a cassette; alignment of stamp and substrate (if needed); embossing; cool down; de-embossing; and unloading of stamp and/or substrate to a cassette.

In its standard configuration, the EVG 750™ supports four separate processes for substrate sizes from 100 mm up to 200mm. The first of these process is a standard, first print/unaligned emboss into a bulk polymer substrate. The second supported process involves a first print/unaligned embossing into a thin polymer film spun on to a substrate, e.g. silicon. The third process is an aligned embossing process where a silicon substrate, having pre-defined alignment keys, with a spun-on polymer layer is embossed using a working/soft stamp with corresponding alignment keys. The fourth, and most complicated, process is a double-sided, aligned imprint into a bulk polymer substrate enabling applications such as multi-layered fluidic circuitry and optical elements for, as an example, integrated optofluidic devices. Although not discussed in the results of this paper, the alignment accuracies of less than 10 um (post-emboss) have been demonstrated.

## **III. AUTOMATED DE-EMBOSSING:**

The implementation of an automated, reliable de-embossing mechanism is key to moving hot embossing applications into a truly high volume environment. Processes for achieving automated de-embossing, such as an “air knife” method, have been proposed by others [3] but this process may experience some issues in regards to handling both substrate and stamp post-embossing. The method for de-embossing employed in the EVG 750™ shows great promise for extended reliability in a manufacturing environment due to the fact that the tool relies on a mechanical de-embossing arm and uses a consistent de-embossing process flow technique

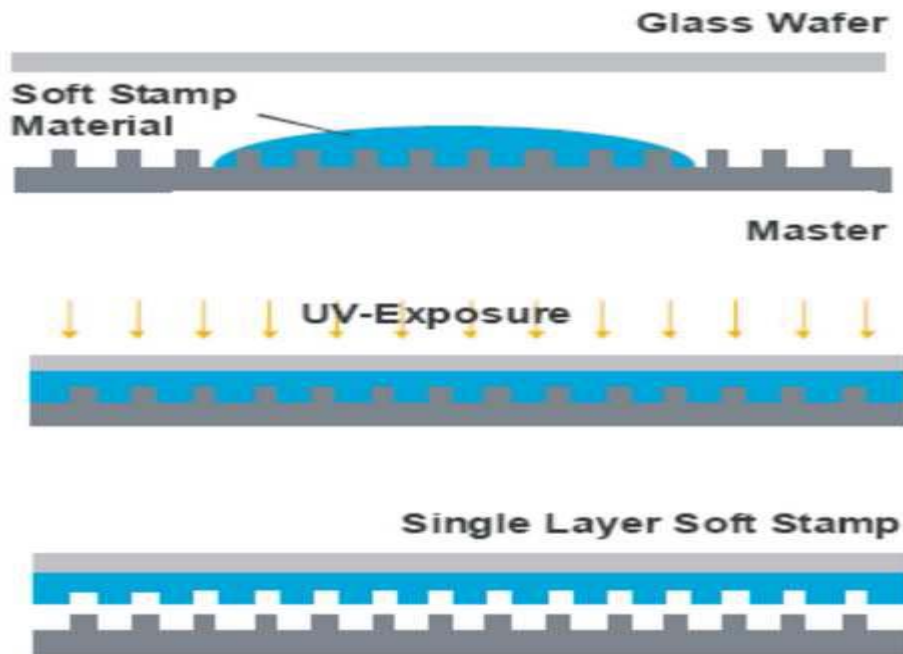
regardless of the type of stamp, type of substrate or type of embossing process flow that is employed. In the simplest process flow, the substrate rests on a vacuum chuck at the bottom of the imprint chamber and the stamp (hard or soft) is affixed to the top of the chamber via vacuum as well. After embossing and cool down, the vacuum is released on the substrate and the substrate remains fixed to the stamp at the top of the imprint chamber as the imprint mechanism moves the top and bottom chucks into separation. The chamber then opens and the de-embossing arm moves in under the substrate and performs the de-emboss process with a knife edge to begin the mechanical separation while the de-embossing arm uses a bellows concept to apply a “tilt” force and then complete the de-emboss of the substrate from the stamp. Thus this same de-embossing concept can be applied to all four processes mentioned in section II. The only variation occurs in the process of double-sided embossing into polymer sheets where a pneumatic pin is employed to assure that the bottom stamp (vice the top stamp) and polymer substrate undergo separation. This assures that the substrate is attached to the top stamp when the de-embossing arm enters the chamber. This pin applies a force to the center of the substrate through a hole in the bottom stamp assuring preferential separation of the bottom stamp and substrate.



**Figure 1:** Fully-automated EVG750 Hot Embossing System for industrial applications

#### **IV. RESULTS OF BULK POLYMER IMPRINTS:**

Soft stamps were fabricated from both Ni masters and masters made of lithographically patterned photoresist. Figure 2 shows the basic process flow for the working stamp fabrication.

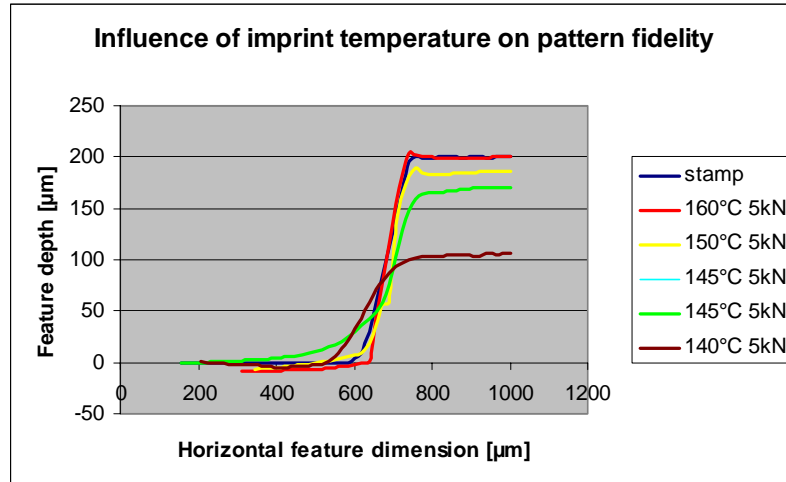


**Figure 2:** Basic Process for Soft Stamp Fabrication

The process flow for the soft stamp fabrication is as follows. The UV-curable soft stamp material is puddle dispensed on to the hard master. A glass wafer is then brought into contact with the master for a pre-determined dwell time that allows the stamp material time to evenly spread out and fill the interface between the glass wafer and hard master. This system is then flood exposed with UV light from the glass wafer side on a typical mask aligner such as the EVG 620™, EVG 6200™ or the EVG IQ Aligner™, thus cross-linking the polymer precursor and forming the soft stamp. The soft stamp is then separated mechanically from the hard master. The resist master was treated with an anti-stiction layer to assure residue free separation; no such treatment was required with the Ni master.

The next step was imprinting directly into a set of bulk polymer substrates, specifically cyclo-olefine copolymer (COC), Zeonor 1060R with a  $T_g$  of 139 °C. This particular polymer is one of the preferred polymers for microfluidic applications due to its chemical resistance and excellent optical properties [4]. The soft stamp was fabricated using a 150 mm master with features lithographically defined into a negative tone SU-8 3025 resist. The relevant feature sizes were 200  $\mu\text{m}$  wide and 200  $\mu\text{m}$  tall. To explore the influence of temperature and force, hot embossing with the working stamps was done at temperatures from 140 °C to 160 °C with imprint forces of 5 kN and 10 kN. Figure 3 shows the dependence of the imprint fidelity on imprint temperature at a constant force of 5kN.

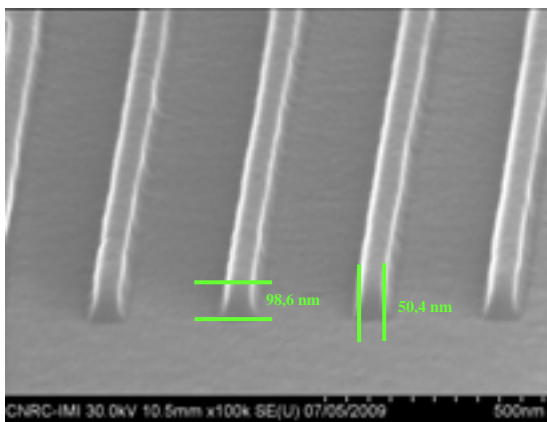
From Figure 3 it is readily apparent that a minimum embossing temperature of 160 °C was required to have good pattern fidelity transfer into the Zeonor 1060R substrate with the working stamp. The graph of 10 kN force yielded a similar response as seen with 5 kN constant force. Thus all further imprints were performed at 5 kN force to minimize mechanical stresses on the working stamp.



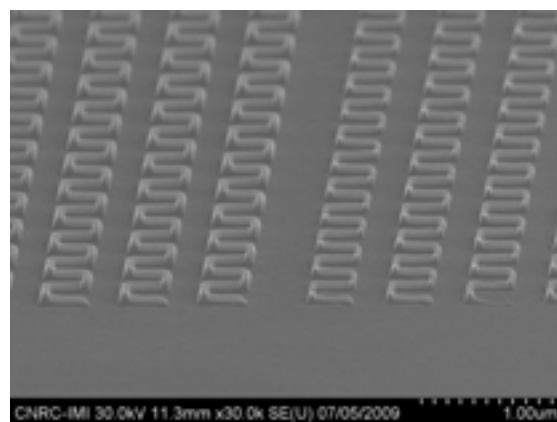
**Figure 3:** Influence of embossing temperature on pattern fidelity with working stamp at constant force of 5kN.

### V. RESULTS OF SPIN-ON POLYMER IMPRINTS:

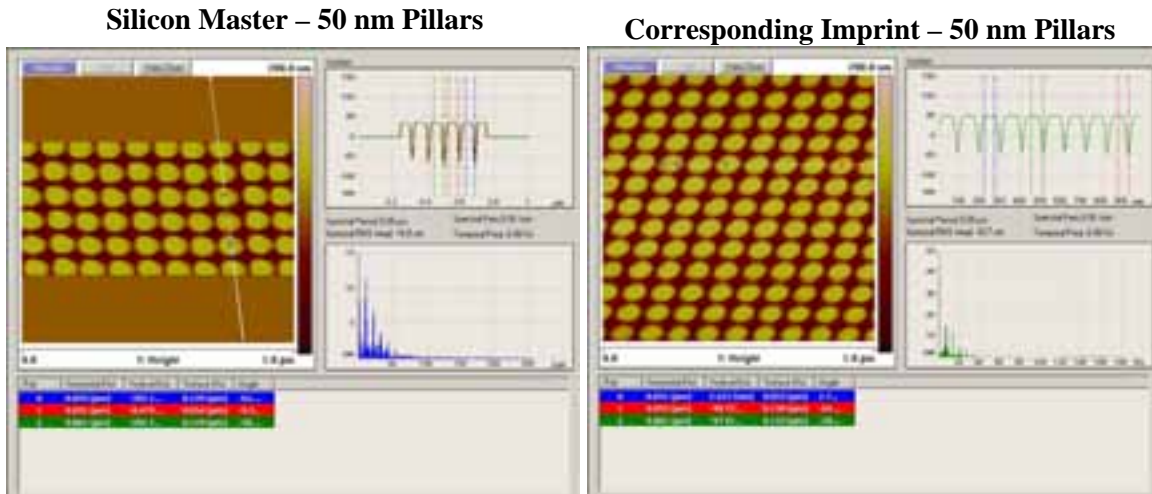
For these set of experiments a hard, 100 mm silicon master with e-beam features written down to 50 nm and with aspect ratios of 2:1 was investigated. The imprint resist chosen for the experiment was *micro resist technology's* mr-I-8030. The imprints were performed at 130 °C and 25 kN, 15 kN and 5 kN. After process optimization, all target patterns were able to be resolved. Figure 4 shows 50 nm lines with 2:1 aspect ratios and excellent demonstrated fidelity. Figure 5 shows 100 nm and 50 nm structures resolved on a silicon substrate. Finally, figure 6 shows AFM measurements of 50 nm pillars on the silicon master compared to the imprint of the same features.



**Figure 4:** Imprint of spin-on resist of 50 nm lines with 100 nm height with associated fidelity measurements – force of 5 kN.



**Figure 5:** 100 nm and 50 nm meander structures – force of 5 kN.



**Figure 6:** Comparison of 50 nm features on silicon master versus the same features imprinted with working stamp.

## VI. CONCLUSION:

Fully automated hot embossing and, critically, fully-automated de-embossing have been demonstrated successfully employing a novel working/soft stamp technology. The use of these low surface energy stamps allow for automated hot embossing of both bulk polymers and spun-on resist layers. The soft stamps were successful in defining both large feature sizes (several microns) as well as very fine feature sizes (down to 50 nm). This soft stamp technology offers many significant advantages over current hard stamp processes which should allow for their rapid adoption into high volume applications including: inherently low surface energy; optical transparency; multiple usage capability; and compliance to substrate TTV.

## VII. ACKNOWLEDGEMENTS:

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