Industrial Applications Demanding Low and High Resolution Features Realized by Soft UV-NIL and Hot Embossing

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ABSTRACT

There are several applications either currently in production or in late stage R&D, for UV-based Nanoimprint Lithography (UV-NIL) and Hot Embossing (HE) that require a full-field imprint technology in order to make these processes either feasible or cost-effective. These applications cover a wide range of features sizes from the millimeter range down to sub-100 nm. Because of the total thickness variation (TTV) associated with the imprinted substrates, full-field imprinting requires fabrication of a “soft” or “working” stamp from a “hard” stamp usually made from materials such as nickel, quartz or silicon. Several materials and processes have previously been identified that allow for full-field imprinting, however, these materials all have drawbacks associated with them that hinder their movement into High Volume Manufacturing (HVM) environments. EV Group Inc (EVG) has, in cooperation with our NILCOM™ partners, identified a novel set of polymeric materials and stamp fabrication processes that allow for full-field imprinting solutions suitable for these HVM environments. These materials have proven effective for imprinting at both millimeter feature sizes all the way down to 50 nm – full field. 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 imprint lithography into industrial applications.

Key Words: Nanoimprint, Hot Embossing, UV-NIL, soft UV-NIL, HE, sub-100 nm features, soft stamps, working stamps, de-embossing, large area imprint, full-field imprint.

INTRODUCTION

As imprint lithography applications move into manufacturing environments, there are several applications that are moving towards full-field imprint due to the throughput and process advantages afforded by this method over traditional step and repeat imprinting. The move to full-field imprinting is usually a necessary step for cost-effective manufacturing whether the applications are for fine resolution (e.g. photonic crystals or patterned media) or larger feature sizes (e.g. micro-lens for CMOS image sensors). Traditionally, achieving fine feature resolution (< 100 nm) with UV-NIL has been accomplished using hard, quartz stamps [1]. The non-planarity that is associated with standard substrates limits the active area of these stamps to ~ 25 mm x 25mm - requiring a step and repeat approach to imprinting the entire substrate surface [2]. While the step and repeat process is necessary for certain applications requiring fine alignment, it is time consuming, requires specialized equipment sets to accomplish and can encounter stitching issues for certain devices. Fine features sizes of less than 100 nm can also be realized with hot embossing into spun-on polymer resists. The challenges here include, not only the TTV of the imprinted substrate, but also the de-embossing of the stamp after the resist has cooled to below Tg [3]. Additionally, there are several structuring processes at larger feature sizes, up to the millimeter range, that use imprint lithography to achieve a desired device form factor. All of these applications can take advantage of the higher throughput and process benefits (e.g. lack of stitching requirements) afforded by a full-field imprint.

Full-field imprinting is typically realized by the fabrication of a “working” or “soft” stamp using a hard stamp as the template also known as the “master”. This hard master can be of various materials such as nickel, quartz or silicon. The patterning of the master for fine resolution is usually performed via e-beam lithography. For larger feature sizes, master fabrication can employ other methods such as standard optical lithography or diamond turning. This working stamp can then be used in a full-field imprinting process commonly termed as “soft UV-NIL”.

In order to provide an effective, full-field imprint the working stamp must have the ability to conform to the TTV of the imprinted substrate while maintaining the fidelity of the desired features defined by the master stamp and have a low surface energy to facilitate the de-embossing process. Typically, working stamps fall into two groups: soft, polymeric stamps and hard, flexible stamps. Both methods face issues in their fabrication and during the imprint process that can make their transition to high volume manufacturing environments challenging. For instance, soft working stamps are typically made from Polydimethylsiloxane (PDMS) because this material provides a low surface energy and good conformal qualities. But, PDMS requires a long, thermal cure under pressure which is very time consuming and can take several hours [4]. Therefore, this process is not conducive to high throughput applications. The material has other issues like swelling when in contact with organic solvents. It also experiences shrinking during the curing process which requires biasing of the features on the master. Also, since PDMS easily conforms to substrate TTV, it presents challenges when attempting to imprint fine feature sizes. Multi-layer PDMS stamps have been fabricated that allow for sub-100 nm feature sizes, however, the compliance of the material still presents challenges for maintaining good pattern fidelity during imprint [5].

Thus, in order to achieve high pattern fidelity in the transfer process, hard and flexible working stamps can be used. These stamps are typically made of thinned, and thus flexible, glass with the master stamp pattern transferred into the imprinting surface through an imprint and etch process [6]. While this method allows for fine feature sizes (sub-50 nm) to be transferred to an imprint resist with good fidelity, these stamps have several issues that make them undesirable for manufacturing applications. Firstly, their fabrication typically requires an imprinting and etch step into the hard substrate – which is costly and time consuming. Secondly, an anti-stiction layer needs to be applied and monitored during processing to assure proper de-embossing which adds additional equipment and process steps. Finally, the thickness of these substrates makes them delicate and difficult to handle.

In this paper, we, in collaboration with our NILCom™ partners, will show results from engineered, polymeric "working stamps" fabricated with a novel set of materials and with demonstrated resolution down to 50 nm over an area of up to two inches. These materials are either currently commercially available or in pilot production stage. In addition to the benefit of high resolution, these materials offer several other processing and cost-of-ownership benefits when compared with competing solutions - including faster and simpler fabrication. The working stamp can be made directly from the master. There is no need for imprinting, etching or thermal cure. Also, one can fabricate sub-masters from the original working stamp using the same class of materials - providing greater flexibility for the master fabrication. The working stamp (and sub-masters) can be fabricated very quickly (a matter of minutes) using only a standard mask aligner as the materials only require UV curing. The stamps have shown the ability to handle multiple imprints per stamp (> 100 imprints). Additionally the materials, like PDMS, have inherently low-surface energies so an anti-stiction coating does not need to be applied or monitored during imprint processing. These materials have great processing flexibility. For example, they can be used to process large features (e.g. millimeter size micro-lenses). And finally, to demonstrate the material's process flexibility and low surface energy, these materials have also been used for hot embossing into spun-on resists with resolution down to 50 nm feature sizes.

EQUIPMENT

The set of materials that are being demonstrated as working stamps for this paper are UV curable materials and thus can be fabricated directly from the master stamp on the same mask aligners that are used for the soft UV-NIL process. The processes discussed in the Results section of this report have been demonstrated on both the EVG620 and the EVG IQ Aligner mask alignment systems (Fig. 1, 2). The EVG620 can handle substrate and stamp sizes from pieces up to 150 mm. The IQ Aligner is designed for substrate sizes from 100 mm to 300 mm. Both systems are capable of semi-automated and fully-automated configurations for soft UV-NIL applications.

Fig. 1: Semi-automated EVG620 soft UV-NIL system for R&D and pilot line production

Fig. 2: Fully automated IQ aligner for soft UV-NIL industrial applications

In addition to the soft UV-NIL processes, these materials have also been tested for hot embossing applications on the EVG750 (Fig. 3). The EVG750 is the first commercially available, fully-automated hot embossing system. It can provide high force – up to 600kN – with 120 kN being the standard configuration. The tool also provides top and bottom side rapid heating capability up to 250 ºC. Rapid top and bottom side cooling is also part of the standard configuration.

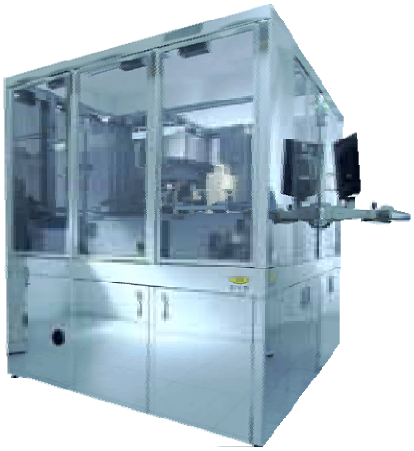

Fig. 3: Fully-automated EVG750 Hot Embossing System for industrial applications

STAMP FABRICATION

The working stamp fabrication takes place on a standard mask aligner. The patterned master is simply placed on the bottom chuck in the aligner and a blank mask backplane is loaded into the mask holder. The uncured stamp material is then puddle dispensed on the master stamp. The glass backplane and the master stamp are then brought into contact and a low contact force of roughly 100N is applied. Depending on how the tooling for the mask aligner is configured, a low vacuum (~ 5 to 10 mbar) can also be applied but is typically not necessary. Once the force has been applied and the resist has spread to the desired coverage of the stamp-backplane interface, the material is flood exposed with broadband UV light. The material is cured within approximately one minute and the fabricated working stamp and can then either be separated from the master stamp automatically in the mask aligner or manually de-embossed outside the mask aligner.

Another useful aspect of these working stamp materials is that, with certain facile process adjustments, one can fabricate another working stamp from a working stamp that was initially fabricated off the master stamp while maintaining pattern fidelity. There are several phrases that have entered into the technical lexicon that describe the “lineage” for this working stamp process flow. Thus, the working stamp fabricated from the master stamp is also called either the “sub-master” or the “daughter” stamp. And, if a working stamp is fabricated from this “sub-master/daughter” stamp it is then called a “sub-sub-master” or “granddaughter” stamp. The ability to fabricate a granddaughter stamp from a daughter stamp with the same UV curable material set affords the user great flexibility when fabricating the hard master stamp. In Fig. 4, it is apparent that one can use this technique to imprint positive features into resist by using a master with negative features – which is typically much easier to fabricate than a master with positive features. This can be accomplished with these working stamps while still maintaining excellent pattern fidelity (see the RESULTS section).

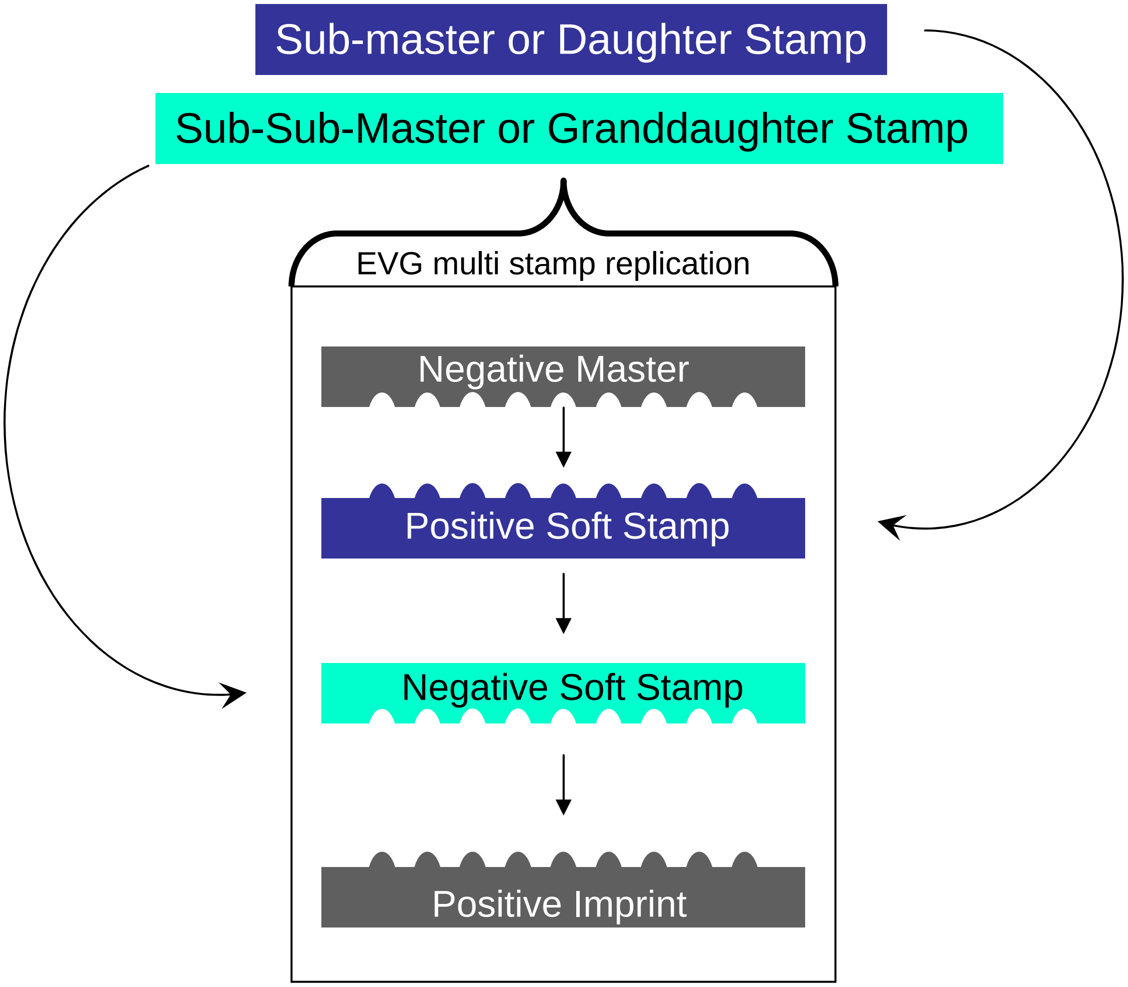

Figure 4: Replication process for a “lineage” of working stamps from a hard master

RESULTS

The soft UV-NIL process flow described above in Fig. 4 was tested on an EVG mask aligner using a standard silicon *NIL Technology* master, a commercially available resist from *micro resist technology* and the UV curable working stamp polymers. A daughter stamp was fabricated on the EVG620 using the master. Then a granddaughter stamp was fabricated from the daughter stamp. The total time for completion of these processes was less than 10 minutes. The granddaughter stamp was then imprinted into the resist using the same EVG620. The resulting imprints were then analyzed on an atomic force microscope (AFM) across a total of 75 measurements. The AFM results showed that the granddaughter stamp material was able to imprint features from the hard master stamp into resist with resolution down to 50 nm and with pattern fidelity of approximately 5%. The granddaughter stamp and the imprinted silicon substrate were successfully de-embossed in the aligner in an automated fashion.

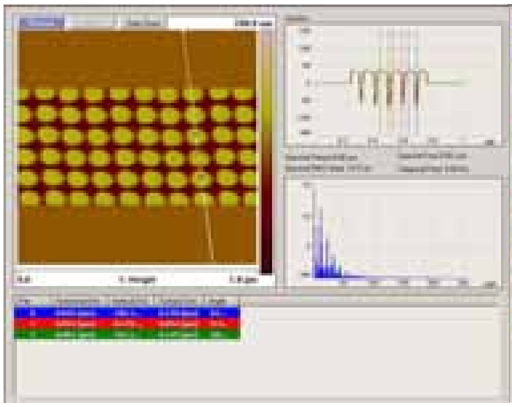

Figure 5: AFM image of the silicon master with dots (50 nm in diameter and 98 nm in height) used for working stamp fabrication

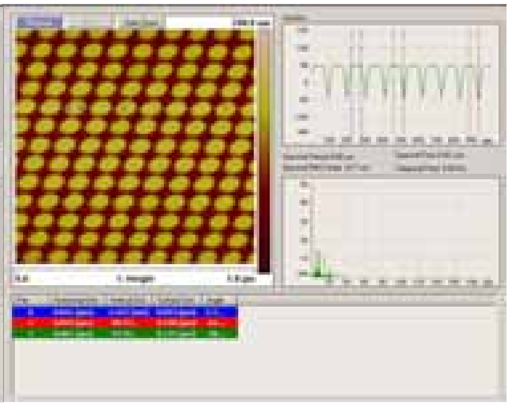

Figure 6: AFM image of the corresponding imprint on a silicon substrate by using a granddaughter working stamp from the silicon master shown in Figure 5

Additionally, a hot embossing test was performed on the EVG750. The purposes of this test were to both understand how the working stamp materials perform under hot embossing conditions as well as to gain an empirical understanding of the limits of the de-embossing capability of the working stamp materials. The same *NIL Technology* stamp was used once again to fabricate a working stamp by the previously described method. The backplane with the patterned working stamp material was then loaded into the EVG750 and an imprint was performed at 150 ºC into a commercially available *micro resist technology* resist that had been spun onto a silicon wafer. The resulting imprint (Fig. 7) allowed for facile, automated de-embossing of the stamp post-imprint without any residuals on the stamp or the imprinted wafer. Typically, automated de-embossing of such fine features into a spun-on HE resist layer presents significant challenges due to the high surface area in contact between resist and stamp.

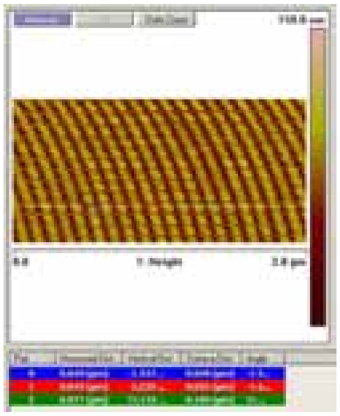

Figure 7: AFM image of imprinted features with 50 nm resolution

As mentioned above, these working stamp materials can imprint both small and large feature sizes. Below (Fig. 8 and Fig. 9) are images of a 200 mm glass wafer imprinted with micro-lenses for wafer level CMOS camera fabrication. Automated de-embossing at 200 mm is a proven process for these materials and 300 mm automated de-embossing has been demonstrated in the IQ Aligner as well. This is an application already in a manufacturing environment where the material of choice for the working stamp is typically PDMS. The ability to use these alternative materials will allow for faster fabrication of the working stamp as well as other processing advantages mentioned in the Introduction.

Figure 8: Image of an array of micro-lenses (diameter of lenses: 1 mm, height of lenses: 500 µm) imprinted with working stamp on 200 mm glass wafers

Figure 9: Image of an array of micro-lenses imprinted with working stamp on 200 mm glass wafers (close-up from figure H)

CONCLUSIONS

Full-field soft UV-NIL and hot embossing was successfully demonstrated for large and fine feature resolution using a novel set of polymeric materials for the working stamps. These materials are either already commercially available or sit in the pilot production stage. They offer several advantages over current working stamp technologies for industrial applications. These advantages include: inherently low surface energy (no anti-stiction layer needed); fast fabrication directly from the master stamp – no imprinting or etching required; fabrication capability on the same platform employed for the UV-NIL process; the ability to make granddaughter stamps and excellent imprinted pattern fidelity.

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