Outline of Liquid-Transfer Imprint Technology and Advanced Processes

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Nanoimprint lithography can be used as a tool for semiconductor lithography. However, problems still remain in respect of the thickness of the residual layer. Liquid-transfer imprint lithography (LTIL) is one candidate for solving such problems. The principle of LTIL involves partial removal of the UV-curable resin in the liquid phase, permitting control of the thickness of the resin layer on the film mold. After removal of the excess resin, the film mold with a thin layer of UV-curable resin is contacted with the target substrate. This process is very simple, permitting its application in various methods and with various types of equipment, such as roll-to-substrate, roll press, or roll-to-roll machinery. Several types of resin-removal and stacking methods are possible. The machinery and associated techniques have a wide range of applications. LTIL has considerable potential, because transfer with no residual layer is possible, a result that is very useful in semiconductor lithography.

Keyword: liquid-transfer imprint lithography, nanoimprint lithography, UV-curable resin, film mold, residual layer

1. Introduction
Nanoimprint lithography (NIL) is a candidate process for use in semiconductor lithography [1]. Ultraviolet-NIL (UV-NIL) [2] is particularly suitable for use in semiconductor lithography because UV-NIL can be performed at room temperature and low pressures. However, problems remain with respect to residual layers. The residual layer is the portion of the imprint between the bottom of the grooves and the substrate. This layer must be removed in a semiconductor process, so it is desirable that it is as thin as possible. Liquid-transfer imprint lithography (LTIL) is one candidate for solving the residual-layer problem [3]. Although it was first reported as recently as 2013, LTIL is now widely used in a range of applications. Here, we give an outline of the LTIL process and we review various advanced LTIL processes.

2. The LTIL Process
An outline of the LTIL process is shown in Fig. 1. The LTIL process uses a soft film mold, usually consisting of poly(dimethylsiloxane) (PDMS), which can be peeled off the UV-curable resin. First, the liquid UV-curable resin is spin-coated onto a sacrificial film or substrate to permit control of the thickness of the resin layer [Fig. 1(1)]. The film mold is then pressed onto the UV-curable resin [Fig. 1(2)]. In normal UV-NIL, the resin is irradiated and cured by UV radiation at this stage, whereas in LTIL, a different process is used. In LTIL, the film mold is peeled off the liquid UV-curable resin to remove excess resin [Fig. 1(3)]. At this stage, a thin layer of liquid UV-curable resin remains on the film mold, which is then placed onto a target substrate [Fig. 1(4)]. The film mold is pressed onto the substrate and the resin is cured by UV irradiation [Fig. 1(5)]. After curing, the film mold is released from the substrate, leaving an imprint with a thin residual layer on the
target substrate [Fig. 1(6)]. The idea underlying this process is that excess UV-curable resin is removed while it is still in the liquid phase. The film mold is used to facilitate removal of the UV-curable resin. Furthermore, the film mold can be transformed into a curved surface, permitting the fabrication of moth-eye structures on a lens by LTIL [4].

Initially, LTIL was carried out manually, but this has limitations, for example, large-area transfer is difficult. Therefore, the next step was the development of a mechanical process for LTIL. An LTIL process using a roll-to-substrate (RTS) machine is shown in Fig. 2. In this case, the soft film mold is wrapped onto a roll mold. The UV-curable resin is coated onto a sacrificial substrate and contacted from above by the patterned-film roll mold [Fig. 2(1)]. As the roll rotates the mold becomes coated with the UV-curable resin, which remains in the liquid phase [Fig. 2(2)]. When the whole area of the roll has been coated by the rotational motion [Fig. 2(3)], the roll mold is placed on the target substrate [Fig. 2(4)]. The roll mold is then pressed onto the substrate while the resin is simultaneously cured by UV irradiation [Fig. 2(5)]. The transfer process is complete when the whole area has been cured [Fig. 2(6)]. This process permits transfer with no residual layer [5].

**Fig. 1. Outline of the LTIL process**

1. Contact
2. Press
3. Peel off
4. Alignment
5. Press & UV exposure
6. Release

**Fig. 2. LTIL process using a roll-to-substrate machine**

3. **Advanced LTIL Processes**

The key to the LTIL technique is the removal of excess UV-curable resin in the liquid state, and several types of removal are possible. Fig. 3 shows an LTIL process with several resin-removal stages, designed to produce thinner residual layers. This process is similar to that shown in Fig. 1, but the pressing onto the sacrificial substrate [Fig. 3(2)] and the removal of the liquid-phase resin [Fig. 3(3)] are performed repeatedly. After each repetition, a new sacrificial substrate that has no adherent resin is used after the film mold has been peeled off. Subsequently, the film mold contacts the sacrificial layer, which removes excess UV-curable resin.
The design of the RTS-type LTIL machine is complex because the UV source has to be located inside the roll mold. A simpler process involves the use of a roll press. An outline of this process is shown in Fig. 4. The key point of this method is that a roll press is used in the thinning process and the transfer process. The thinning process is shown in Figs. 4(1)–4(3). Spin coating is not necessary in this method. The subsequent transfer process is shown in Figs. 4(4)–4(6). In this case, a roll press is used to contact and press the UV-curable resin onto the target substrate. After pressing, the resin is cured by UV irradiation. By using this roll-press method to control the thickness of the layer of UV-curable resin, a stacked-metal structure can be fabricated. Details of this have been reported elsewhere [6]. Briefly, metal patterns are located at the bottoms of the grooves in the film mold before the roll-press LTIL process is carried out. After transfer onto a polyether film, the metal patterns are relocated to the tops of the transferred layer. Furthermore, by repeatedly performing this process, stacks of transfer layers with metal patterns can be fabricated. A cross-sectional view of an example of such stacked layers is shown in Fig. 5.
In the assembly shown in Fig. 5, a silver dot is present on the top of each pillar in the pattern and the stacked structure consists of five layers. This kind of structure can be used in a plasmonic memory [7,8].

The LTIL process can also be used in roll-to-roll (RTR) UV-NIL. This technique is illustrated in Fig. 6.

![Image of LTIL process](image-url)

**Fig. 6.** The LTIL process on RTR UV-NIL equipment

This process is as follows. First, the UV-curable resin is dropped onto the patterned roll mold [Fig. 6(1)]. The film is then fed and the roll mold is rotated. The nip roll compresses the layer of UV-curable resin. At this stage, no UV irradiation is performed. As a result, excess UV-curable resin is removed leaving a thin layer of resin on the roll mold [Fig. 6(2)]. A second rotation is then carried out, this time with UV irradiation to cure the resin [Fig. 6(3)]. After feeding the whole roll-mold area, a transfer pattern is obtained. By using this RTR UV-NIL for LTIL technique with two resin-removal stages (Fig. 3), a pattern with no residual layer can be obtained, as shown in Fig. 7 [9]. As shown Fig. 7, patterns of nanoscale holes with no residual layer can be obtained by means of the RTR UV-NIL with LTIL process.

![Image of transfer with no residual layer](image-url)

**Fig. 7.** Transfer with no residual layer is possible in RTR UV-NIL by using the LTIL process

4. Conclusion

The LTIL process is a novel technique for the production of thin residual layers. The key to the LTIL process is partial removal of the UV-curable resin in the liquid phase, so various approaches are possible. Our review of various methods and equipment for LTIL has shown that LTIL has considerable potential because it is capable of achieving transfer with no residual layer. In addition, this process can be used to produce stacked layers with residual layers of controlled thickness. The usual material for LTIL molds is PDMS, but other materials can be used. We are now investigating various film-mold materials to improve the durability of the LTIL process.

References