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UV enhanced substrate conformal imprint lithography (UV-SCIL) technique for photonic crystals patterning in LED manufacturing

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ABSTRACT

The global LED (light emitting diode) market reached 5 billion dollors in 2008 and will be driven towards 9 billion dollors by 2011 [1]. The current applications are dominated by portable device backlighting, e.g. cell phones, PDAs, GPS, laptop etc. In order to open the general lighting market doors the luminous efficiency needs to be improved significantly. Photonic crystal (PhC) structures in LEDs have been demonstrated to enhance light extraction efficiency on the wafer level by researchers [2]. However, there is still a great challenge to fabricate PhC structures on LED wafers cost-effectively. Nanoimprint lithography (NIL) [3] has attracted considerable attentions in this field due to its high resolution, high throughput and low cost of ownership (CoO). However, the current NIL techniques with rigid stamps rely strongly on the substrate flatness and the production atmosphere. Those factors hinder the integration of NIL into high volume production lines. UV-NIL with flexible stamps [4], e.g. PDMS stamps, allows the large-area imprint in a single step and is less-sensitive to the production atmosphere. However, the resolution is normally limited due to stamp distortion caused by imprint pressure.

A novel NIL technique developed by Philips Research and Süss MicroTec, substrate conformal imprint lithography (SCIL), bridges the gap between UV-NIL with rigid stamp for best resolution and soft stamp for large-area patterning. Based on a cost-effective upgrade on Süss mask aligner, the capability can be enhanced to nanoimprint with resolution of down to sub-10 nm on an up to 6 inch area without affecting the established conventional optical lithographic processes on the machine. Benefit from the exposure unit on the mask aligners, the SCIL process is now extended with UV-curing option, which can help to improve the throughput dramatically. In this paper, the fabrication of photonic crystal structures with SCIL technique on Süss MA6 mask aligner is demonstrated. In addition, the industrialization considerations of UV-SCIL process in high volume manufacturing are briefly discussed.

1. Introduction

The global LED (light emitting diode) market reached 5.5 billion dollars in 2008 and is dominated by portable device backlighting applications e.g. mobil phones, PDAs, GPS, Laptop, etc. Emerging applications including general lighting will drive the market towards 9 billion dollars by 2011, according to Yole development report. However, the luminous efficiency needs to be improved significantly in order to open the market for LEDs to replace traditional light bulbs [1]. Photonic crystal (PhC) structures in LEDs have been demonstrated to enhance light emission efficiency by diffractive waveguide structures. It is still a great challenge to fabricate PhC structures on LED wafers cost-effectively [2,3].

Nanoimprint lithography (NIL) [4] is a simple method to fabricate nanostructures and it has attracted considerable attentions in many applications due to its high resolution, high throughput and low cost of ownership (CoO). There are several NIL candidates for mass productions in the market: hot-embossing lithography (HEL), UV-NIL [5] with rigid quartz stamps and UV-NIL with flexible stamps [6]. HEL has been discarded from PhC LEDs application due to its thermal cycles and therefore low throughput. UV-NIL with rigid stamps provides excellent resolution down to sub-20 nm. However, the process relies strongly on the substrate flatness and production environment. It is not suitable for patterning of most of the LED wafers, which have roughness of more than 10 μm. In addition, most of the existing LED factories are designed as class 1000 or above, which will limit the yield of the process and increase the CoO of imprint stamps dramatically. UV-NIL with soft stamps, e.g. PDMS stamps, allows the large-area imprint in a single

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step with less sensitivity to substrate flatness and particles. However, the resolution is normally limited due to the stamp distortion caused by imprint pressure.

Substrate Conformal Imprint Lithography (SCIL) [7], a novel NIL technique developed by Philips Research and Süss MicroTec, bridges the gap between UV-NIL using rigid stamps for best resolution and soft stamps for large-area patterning. Based on a cost-effective upgrade on Süss mask aligner, the aligner capability can be enhanced to nanoimprint with sub-50 nm resolution up to 6 inch diameter area without affecting the established conventional optical lithographic processes on the machine. In this paper, the process details of SCIL technology and the imprint tooling are briefly described. Additionally, the introduction of SCIL into high volume manufacturing of high brightness LED (HB LED) is discussed.

2. SCIL principle

In order to reduce the CoO (cost of ownership) of large-area imprint stamps, SCIL process uses composite working stamps consisting of a glass carrier with patterned rubber [8] which are replicated from the original master pattern. Philips Research developed a SCIL master replication tooling (MRT) and automatic separation tooling, which allow the end-users to produce high quality SCIL stamps themselves from their own masters; this tooling is available from SUSS MicroTec Lithography GmbH. Before stamp replication, the silicon master surface is modified with 1H,1H,2H,2H-Perfluorodecyltrichlorosilane chemistry as anti-adhesive layer [9] in order to protect the master against contaminations of PDMS residuals. The PDMS working stamp is then replicated from the master and simultaneously adhered onto a thin glass carrier in MRT. Fig. 1 shows a finished composite SCIL stamp. This geometry has the following advantages: one hand, the in-plane rigidness of the glass carrier avoids lateral stamp deformation caused by vacuum fixing on the stamp holder; on the other hand, the flexibility in the out-of-plane direction of the thin glass and PDMS allows conformal imprint over large areas.

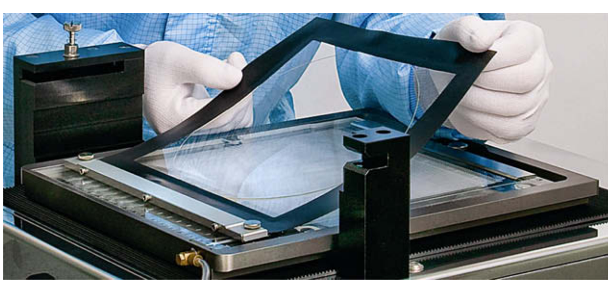

Fig. 1. Photograph of loading a flexible SCIL stamp onto a SCIL stamp holder.

Although the PDMS stamp can compensate the waviness of the substrate, directly contacting a large-area stamp during replication can lead to non-conformal imprint or "bubbles" in case of using perpendicular imprint process. To achieve a substrate conformal contact between working stamp and substrate, the SCIL process relies on a sequential imprinting process where capillary forces help to pull the stamp into the liquid imprint resist. The approaching of the flexible stamp starts from one side and spreads to the whole stamp subsequently by releasing the vacuum in the grooves step by step and applying an small over pressure of 20 mBar on the stamp. (Fig. 2a–c). This sequent contact mechanism prevents the flexible stamp from trapping air and therefore ensures that the stamp follows exactly the undulating topography over whole substrate surface. The imprint resists that are used wet the PDMS stamp surface and the resulting capillary forces fill up features with resists. The capillary forces are leading to minimized structure deformation and lateral stamp distortion during the imprint process. In this way sub-50 nm resolution patterns have already been demonstrated. After conformal contact over the entire substrate is carried out, the imprint resist layer is cured by UV exposure or in case of using imprint sol–gel based resists diffusion of the sol–gel solvent into the PDMS stamp (see Ref. [7]). As the PDMS layer is ~5 mm thick compared to a resist layer thickness of ~100 nm solvents do not saturate or swell the stamp. Additionally, solvents diffuse out of the PDMS on stamp release. The automatic separation of the stamp from the substrate is performed by switching on the vacuum in the grooves consequently, which is opposite to the imprint process (Fig. 2d–f). This results in a low force peeling action which removes the stamp from the patterned resist layer and avoids damage to stamp or patterns.

The SCIL imprint tooling is retrofitable on SUSS MA6 or MA8 Gen3 mask aligners (Fig. 3). This upgrade can be installed on-site with very limited efforts. The SCIL process therefore benefits from

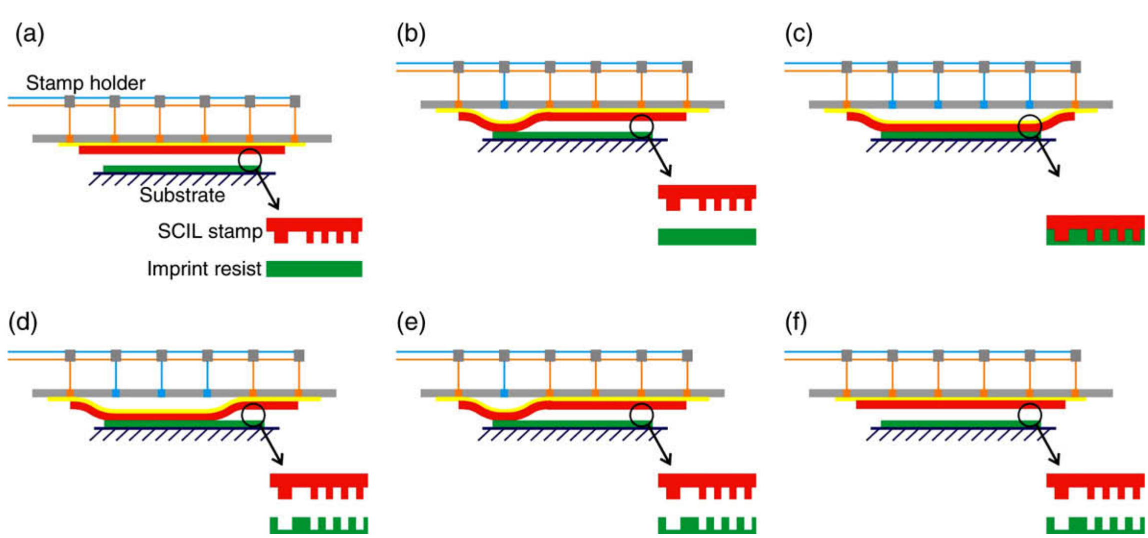

Fig. 2. Schematic illustration of the SCIL imprint and separation sequences. (a) The SCIL stamp is fixed on the stamp holder by vacuum; (b) the imprint process starts from one side of the stamp; (c) the imprint is completed by releasing the stamp holder vacuum grooves one by one; (d) after curing of the resist, the separation process starts from the other side of the stamp; (e) and (f) the separation process is completed by switching on the vacuum in the grooves one by one.