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Research paper

Consecutive imprinting performance of large area UV nanoimprint lithography using Bi-layer soft stamps in ambient atmosphere

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ABSTRACT

For UV nanoimprint lithography (UV-NIL) using polymer soft stamps, imprinting at ambient atmosphere brings additional challenges due to evaporated solvents and possible byproducts resulting from the interaction between the UV light, oxygen and the polymer-based material. Moreover, the Laplace pressure may impact differently on the capillary filling for both positive and negative patterns at atmospheric pressure compared to that in the vacuum. Twenty consecutive imprints using bi-layer Polydimethylsiloxane (PDMS), PDMS/toluene-diluted PDMS, PDMS/X-PDMS, PDMS/vvsPDMS stamps have been tracked and inspected. The imprinting employs a center-to-edge scheme in ambient atmosphere. The results show that high reusability and imprint uniformity can be achieved for at least twenty consecutive imprints using the pure PDMS (PDMS/PDMS) and PDMS/toluene-diluted PDMS. These stamps can overcome the challenges of the interaction between the UV light, oxygen and the polymer-based materials. The Laplace pressure under atmosphere does not hinder the resist filling for such consecutive imprints.

1. Introduction

The application of nanoimprint lithography (NIL) nowadays has been expanded to various fields such as optics [1], MEMS/NEMS [2], solar cells [3], LED industry [4,5], bio life science [6], and structural coloring [7]. The soft UV-NIL, which commonly employs a UV-curable resist cross-linked by UV exposure through a transparent stamp, has been widely exploited due to its immense advantages. Unlike rigid template lacking long-term reusability, numerous soft working stamps can be replicated from a single master and each working stamp can provide multiple imprints. Greater diversity of substrates is suitable for nanostructuring by soft UV-NIL. The soft stamp is able to tolerate small but solid particles on the substrate surface [8]. The flexibility of soft stamps enables the potential of imprints on nonplanar surfaces [9]. In contrast to the rigid stamps, much lower pressure is required to obtain a conformal contact between the stamp and coated resist when using soft stamps.

Imprinting in ambient atmosphere is the simplest condition for soft UV-NIL without complex tools as far as no alignment is required. However, the ambient atmosphere causes additional challenges. For instance, the evaporated solvent in the resist and possible byproducts resulting from the interaction between the UV light, oxygen and the polymer-based material can be encountered. Moreover, the Laplace pressure [10] may impact differently on the resist capillary filling for positive or negative patterns at atmospheric pressure compared to that in an evacuated chamber.

In this paper, performance of up to twenty consecutive imprints at 100 mm size in ambient atmosphere using soft UV-NIL is demonstrated. A hybrid soft stamp consisting of a soft back carrier and a feature layer is used for a center-to-edge imprinting scheme. Materials such as Polydimethylsiloxane (PDMS), toluene-diluted PDMS, X-PDMS and vvsPDMS as the feature layer are comparably characterized by nanoindentation. The reusability of a single soft working stamp and the homogeneity of consecutive imprints on large area (100 mm) in ambient atmosphere are demonstrated.

2. Experimental setup

The surface of a silicon hard master template is coated with 1H, 1H, 2H, 2H-Perfluorodecyltrichlorosilane (FDTS, ABCR GmbH) as anti-sticking layer (ASL). The surface energy correlates with the contact angle of an applied liquid droplet by Young's equation. The contact angle of water on FDTS treated master surfaces reaches 115°, which corresponds well to the literatures [11,12].

A bi-layer soft polymer stamp is replicated from the master. The stamp consists of a 2 mm PDMS back carrier (Sylgard 184, Dow Corning) and a feature layer with thickness of 150 µm. The soft PDMS carrier owns a typical Young's modulus of 0.5–3 MPa [13–16], and PDMS, toluene-diluted PDMS, X-PDMS and vvsPDMS are utilized for the feature layer. The PDMS itself has been widely used as material for soft stamps due to it air permeability, cost efficiency, elasticity, low

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Table 1
The curing conditions of different feature layers.

Curing condition	PDMS			
	PDMS	Toluene-diluted PDMS	X-PDMS	vvsPDMS
Curing temperature	80 °C	80 °C	50 °C	60 °C
Pre-curing of feature layer	30 min	30 min	15 min	30 min
Co-curing of hybrid stamp	2 h	2 h	5 days	10 h

surface energy and so on. It has been reported that lowering the viscosity by toluene improves the wetting ability and hence increases the patterned height of structures [17]. Throughout this work, the concentration of toluene to the PDMS is kept at 40 wt.%. The X-PDMS is a commercial product from Philips whereas the vvsPDMS is a product represented by 5microns, both of which are aiming for higher Young's modulus to keep the good fidelity of nanoscale patterns. The feature layer material is coated on the surface of the master, pre-cured and thermally co-cured with the PDMS carrier which is prepared beforehand. The curing conditions of different feature layers as recommended by the manufacturers are shown in Table 1.

A variety of soft UV-NIL systems have been demonstrated. The well-known systems are such as the SUSS MA series using the substrate conformal imprint lithography (SCIL) developed by Philips and SUSS MicroTec [8], the facilities employing the SmartNIL (EVG) [18]. Other embedded modules are engaged with different imprint principles relying on, for instance, bowing of the substrate (HP) [19], parallel contacting (GESIM) [20] bowing of the stamp (CNI Tool, NILT) [21], and the air cushion press principle [22], etc.

In this work, a center-to-edge scheme taking advantage of the bowing of the soft stamp is employed for the imprinting (GD-N-03, Gdnano Ltd.). A low pressure of approximate 0.5 kPa is applied to the soft stamp from the sealed backside chamber. A contact is brought between the stamp and substrate at the very center due to the bowing of the stamp. The air is squeezed to the side gradually such that the air bubbles do not challenge the contacting. Full size conformal contact is obtained from the center to the edge of the substrate following the topology of substrate in ambient atmosphere. After full imprinting, the resist is cross-linked with UV. The detaching is carried out by driving down the substrate at low velocity. The imprinting scheme is graphically depicted in Fig. 1.

3. Results and discussion

3.1. Characterization

For the pure PDMS (PDMS/PDMS), PDMS/toluene-diluted PDMS, PDMS/X-PDMS, and PDMS/vvsPDMS stamps, the UV transmission at wavelength at 365 nm is measured in a nitrogen-purged UV–Vis-NIR spectrophotometer (Cary 5000, Varian). The transmission for all compositions is above 85% for the employed stamp thickness, which meets the requirement for an effective UV exposure.

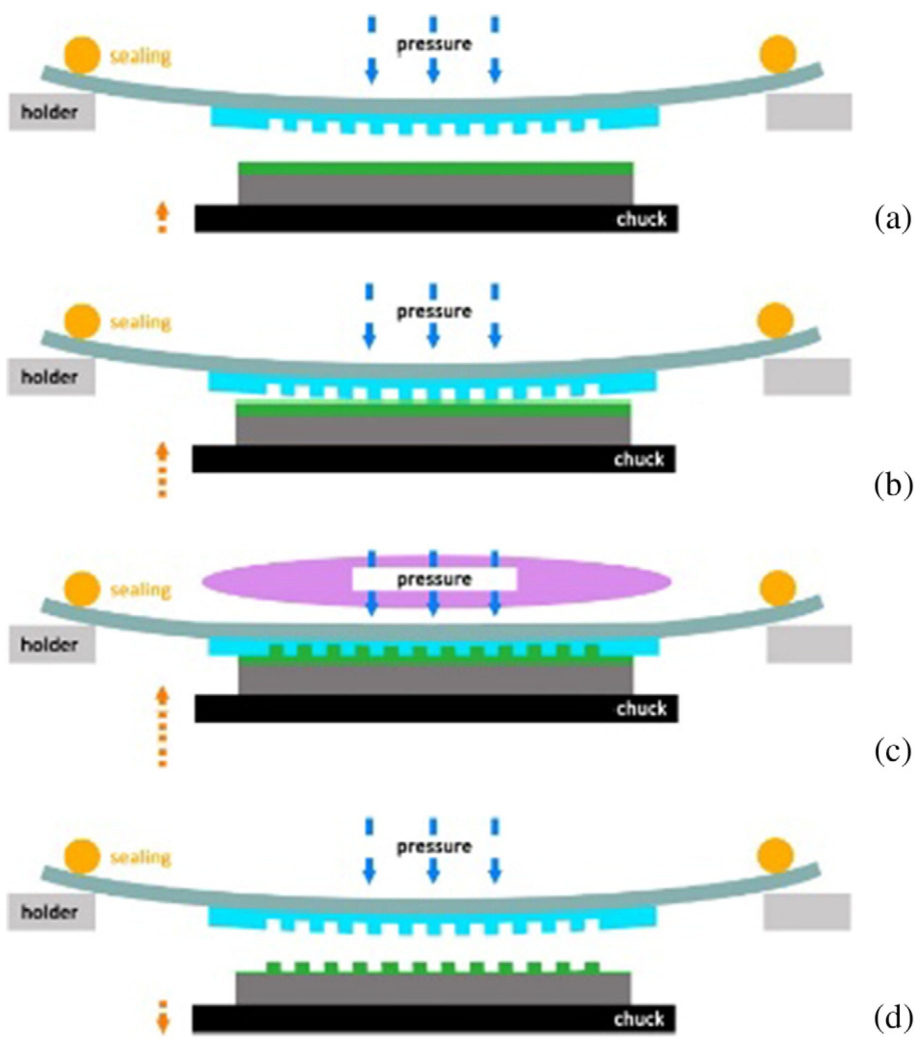

Fig. 1. Schematic diagrams of the imprinting principle of the center-to-edge scheme: (a) positioning; (b) contacting; (c) imprinting and UV exposure; (d) detaching.