Evolution of mound and air bubble formation in thermal nanoimprint

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Air bubbles, arrays of voids and mounds with different forms and depths give evidence of the range of dynamic physical effects during the molding of micropattens in thin polymer films, ranging from capillary effects, dewetting, trapping of air, and viscous fingering [1]. Micrographs of partially molded resist often only give a rough indication of what happened during the imprint process. They are screenshots of the final state when the polymer reaches its solid state on cooling. If the molding process can be stopped at different times, then these screenshots can be combined to a movie sequence of different states of an imprint. This evolution can be observed in a single imprint, when a pressure gradient results in different states of imprint at different locations. This is because according to Stefan's law (see Eq. 1), for simple setups, pressure p and time t can be interchanged (h_0 initial polymer height, η_0 the zero shear viscosity, s protrusion width).

$$\frac{1}{h^2(t)} = \frac{1}{h_0^{\;2}} + \frac{2p}{\eta_0 \cdot s^2} \cdot t \qquad (1)$$

If a regular structure, e.g. a pillar array with a few μms resolution is imprinted, then micrographs of adjacent, but identical structures with constant increment, can be cross-faded and combined into a movie which illustrates the evolution of the pattern.

For the fast heating and cooling we have used an adapter in our Jenoptik HEX03 machine with a spring mechanism, which is described in more detail in [2]. It allows for inserting the stamp/substrate stack without touching the surface of the heated press plates, and by closing the press, the heating to the imprint temperature takes place. At the end of the imprint process, the stack is separated from the bottom plate, which results in an immediate and fast cooling.

Fig. 1 shows a selection of the movie sequence. It shows that during the sinking of the pillars into the film, the polymer displaces the air while flowing around the pillars. In contrast to the sequence shown in [3], where 20 μm square cavities were filled, round air bubbles only form at the end of the molding between the pillars, i.e. when the flowing polymer forces them to minimize surfaces. As in [3] the air finally vanishes. The polymer can flow faster and much more freely than anticipated until now, and in a more complex way. In our contribution, we will discuss the evolution of single patterns including artifacts (Fig. 2), which correspond to those observed in [1].

The current setup only gives a rough quantitative estimate of pressure and time. If these effects can be predicted by simulations, then structure filling can be tuned by clever design and choice of process parameters. A better way to elucidate the polymer behavior would be to observe the formation of patterns in real time through a transparent embossing stamp, was done in [4]. However, our method is more appropriate for current presses and can be scaled down to sub-μm dimensions.

[1] H. Schift, L.J. Heyderman, M. Auf der Maur and J. Gobrecht, *Pattern formation in hot embossing of thin polymer films*, Nanotechnology 12, 173-177 (2001).

[2] H. Schift, L H. Schift, S. Bellini, J. Gobrecht, F. Reuther, M. Kubenz, M. B. Mikkelsen, K. Vogelsang, *Fast heating and cooling in nanoimprint using a spring-loaded adapter in a preheated press*, submitted to Microelectron. Eng. (2007).

[3] L.J. Heyderman, H. Schift, C. David, J. Gobrecht, T. Schweizer, *Flow behaviour of thin polymer films used for hot embossing lithography*, Microelectronic Engineering 54, 229-245 (2000).

[4] L.G. Baraldi, *Heißprägen in Polymeren für die Herstellung integriert-optischer Systemkomponenten*, PhD Thesis ETH No. 10762, Zurich, 1994, in German.

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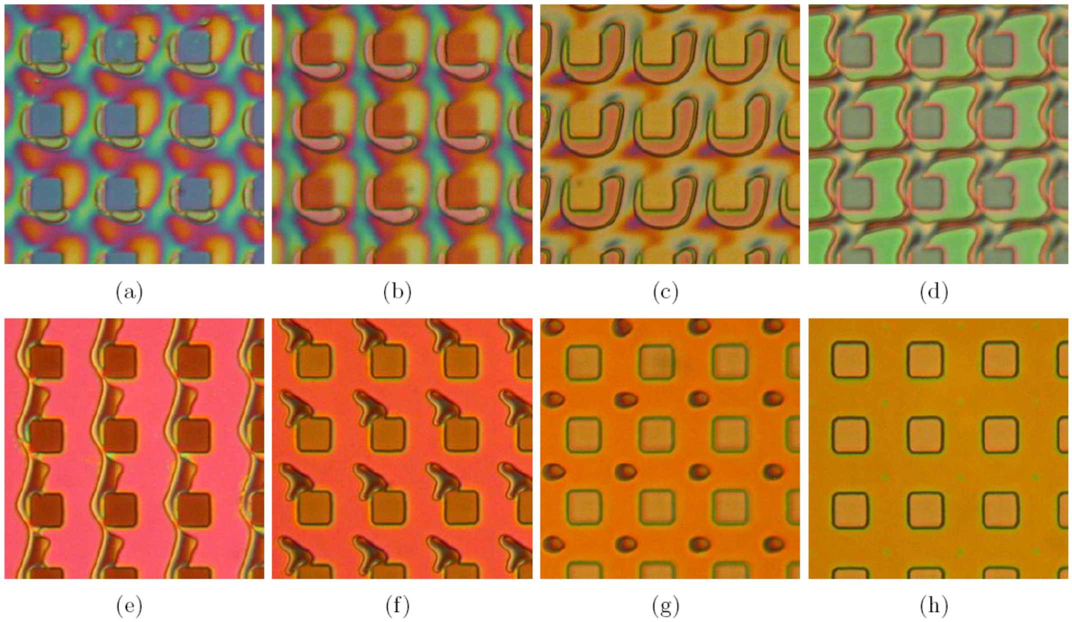

Figure 1. Sequence of micrographs showing the molding of a 5 µm pillar structures. Due to the pressure gradient at the border of a 100 mm wafer, within a few mm different filling states can be observed. Structure: pillar array of 10 µm pitch, 240 nm deep, resist 300 nm, imprint time 60 s.

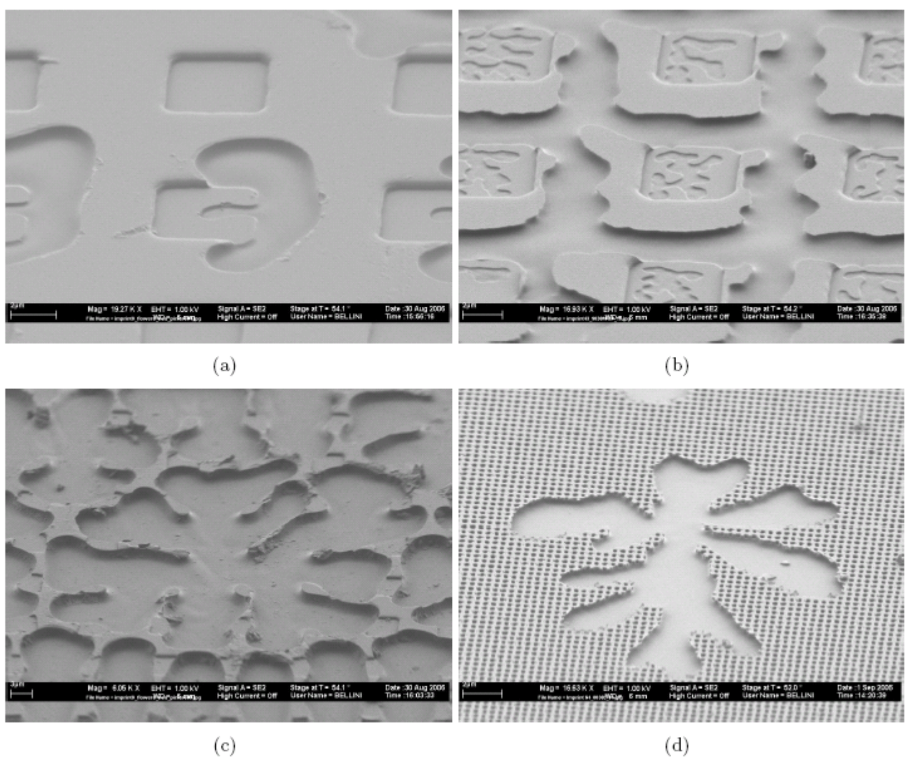

Figure 2. Study of imprint artifacts: (a) air bubble present after molding. (b) incomplete filling of the stamp cavities. (c) flower-like artifacts due to air expanding in viscous resist. (d) artifact in the middle of nanostructures.