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Thermal imprint into thin layers of polymer below the critical molecular weight

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Thermal imprint into thin polymer layers, i. e. the layer thickness is below the level where all cavities can get filled during the imprint process, is beneficial in order to archive a minimum and highly uniform residual layer. Since this method, which we also denote as 'partial cavity filling', produces best results when preferably small structures are imprinted (Fig. 1 left), it is a valuable technique for nanolithography. Small 'negative' structures as displayed in Fig. 1 (right) though are fabricated by imprinting large surrounding elevated structures. That is the reason why nanoimprint lithography (NIL) has to be able not only to imprint structures in the nanometer range but also large structures of several 10 micron at the same time and with sufficient quality.

Unfortunately partial cavity filling is impaired by physical self assembly of the polymer in case that high imprint temperatures are applied[1]. When, however, the temperature is decreased in order to avoid such effects by limiting the polymer's ability to flow, other unfavourable structures develop. Fig. 2 shows that small structures such as 5 μm lines (top row) show a good replication fidelity at 190°C as well as at 170°C and 150 °C. Earlier findings revealed that such imprints easily can be used to invert the patterns by means of lift-off without any previous residual layer removal[2]. Larger structures on the other hand lead to recovery of the polymer after the imprint, which is as more distinctive as lower the imprint temperature is chosen (Fig. 2 bottom row). Of course recovery is not tolerable in case the imprint is used directly as a lithography mask.

The ability of polymers to recover at all is determined by the elastic part of the viscoelastic behaviour of polymers, which again depends on the respective amount of existing entanglements of the polymer-chains. The higher the molecular weight of the polymer is the higher is the number of entanglements. Below the critical molecular weight, M_c, the polymer chains are assumed to have no effective entanglements. Therefore imprints into such polymers may reduce recovery or even are able to avoid it.

We will show imprint results into thin polystyrene layers where the molecular weight is far below M_c (M_W= 1kg/mol, $M_{c\ PS}$= 35 kg/mol). Furthermore we will show that such polymers behave very different from polymers above M_c. Self assembly occurs already at an imprint temperature of only 50°C (Fig. 3 left) in combination with recovery. In contrast, during the imprint of higher molecular weight polymers at temperatures where self assembly develops, recovery does not occur (compare Fig. 2, 190 °C). Thus very low molecular weights may not be able to solve the problems related to partial cavity filling.

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[1] N. Bogdanski et al, *Proc. SPIE* 5504, (2004) 197-203

[2] N. Bogdanski et al, *JVST B* 24 (6), (2006) 2998-3001

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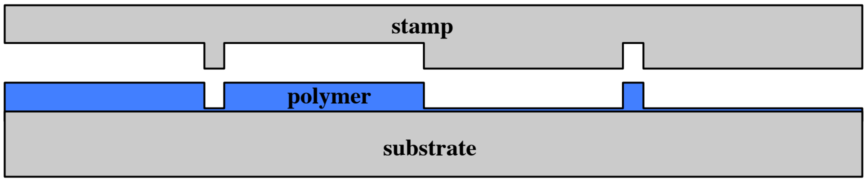

Fig. 1: Scheme of replication by nano-imprint. Left, a ‘positive’, elevated structure in the nm range is replicated by imprinting just the structure itself. Right, a negative structure is replicated by the imprint of large structures.

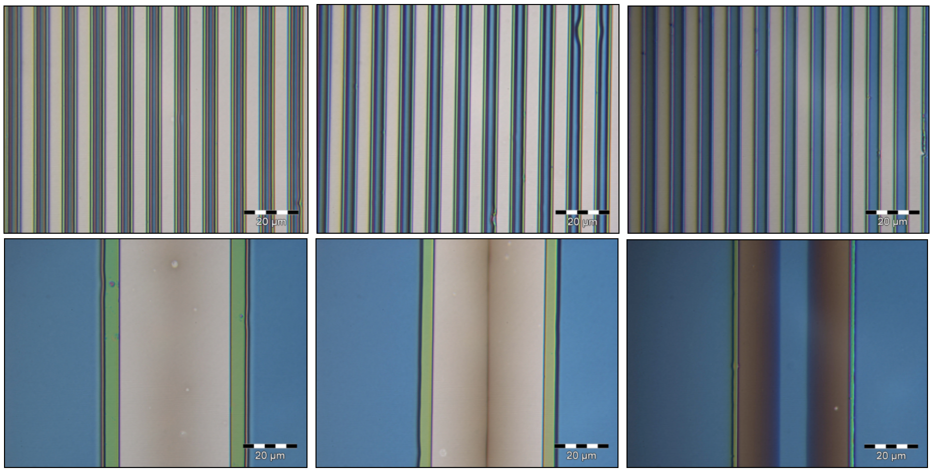

Fig. 2: Imprints of 500 nm high structures into a polystyrene layer (M_w=350kg/mol) of 130 nm thickness at 190°C (left column), 170°C (middle column) and 150°C (right column) imprint temperatures. Due to the limited polymer supply the cavities do not get completely filled. Periodic lines of 5 μm width and 10 μm pitch (top row) are replicated with excellent quality and negligibly low residual layer for all temperatures (bright areas). Large single structures such as the 40 μm line (bottom row) can only be replicated at 190°C with sufficiently low and uniform residual layer. Imprints at temperatures of 170°C and 150°C show an increasing development of non-uniformity due to polymer recovery.

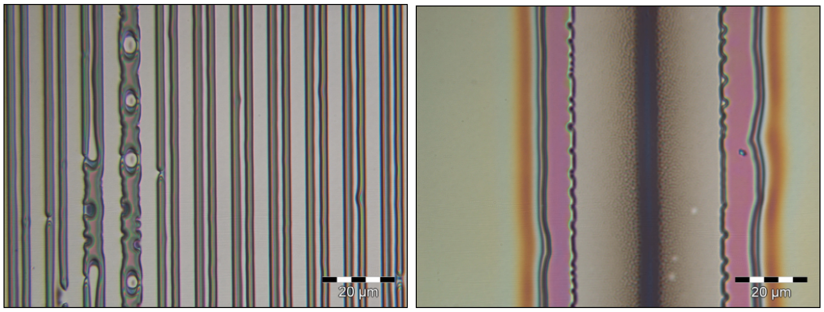

Fig. 3: Imprint of periodic 5 μm lines with 10 μm pitch and a single 40 μm line into a polystyrene (M_w=1kg/mol) layer of 200 nm thickness. The imprint temperature was 50 °C. Despite the small imprint temperature the replication is affected by self assembly of the polymer within the small cavities (left). In addition larger structures still show recovery of the polymer after separation.

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