Hybrid structures achieved by direct writing laser lithography - tuning the contrast and surface topography of grayscale photoresist with nanoimprint lithography

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Direct writing lithography (DWL) using a focused laser beam is a powerful maskless patterning process for fabricating 2 and 2.5 dimensional surface structures via binary or grayscale lithography [1]. In the Heidelberg Instruments DWL 66+ system, the writing speed depends on the choice of the writing mode (WM) which correlates to the required resolution. For example, WM III (max. resolution 1 µm) would be 50 times faster than the high-resolution WM Hi-Res (0.3 µm). Therefore, adding a sub-micron grating structure on top of a resist with a macroscopic structure could result in extreme writing times, and delicate optimization of exact dose values for achieving the right grating depth. An example is the outcoupling waveguide presented in [2], which was a hybrid approach combining thermal nanoimprint lithography (T-NIL) for the grating and DWL. However, in contrast to the PMMA - a thermoplastic polymer suitable for T-NIL and electron beam lithography, positive resists for DWL contain a photosensitive component that degrades easily when heated. Any thermal processing before or after DWL and prior to development requires a thorough analysis of the resulting contrast curve. This fact can be used for simply choosing the maximum temperature for T-NIL, but also to tailor the contrast curve before the DWL exposure.

As a proof-of-concept, we imprinted the ma-P 1275G resist from micro resist technology GmbH, a novolak-based positive resist optimized for grayscale lithography with 405 nm wavelength. For T-NIL, we chose a range of imprint temperatures near its prebake temperature of 105°C, followed by subsequent exposures (Figure 1). The resist contrast to the 405 nm laser decreases with the increasing imprinting temperature (Figure 2). After being processed at 140 °C, well below the 150°C typically used for thermal reflow (after development), the resist loses its sensitivity completely. However, at 120 °C with a contrast value of 0.23, it is still possible to pattern the resist into at least 4 µm depth with a mediate exposure intensity of the system.

The initial results indicate us the potential of achieving complex structures in this type of grayscale resist by combining T-NIL with the DWL lithography. Our next step is to generate grayscale sidewalls, which contain structures that pre-patterned with T-NIL, preferably at a low DWL exposure dose range.

[1] A. Grushina, Adv. Opt. Techn. 2019; 8(3–4): 163–169.
[2] H. Schift, Applied Physics A 121(2) (2015).

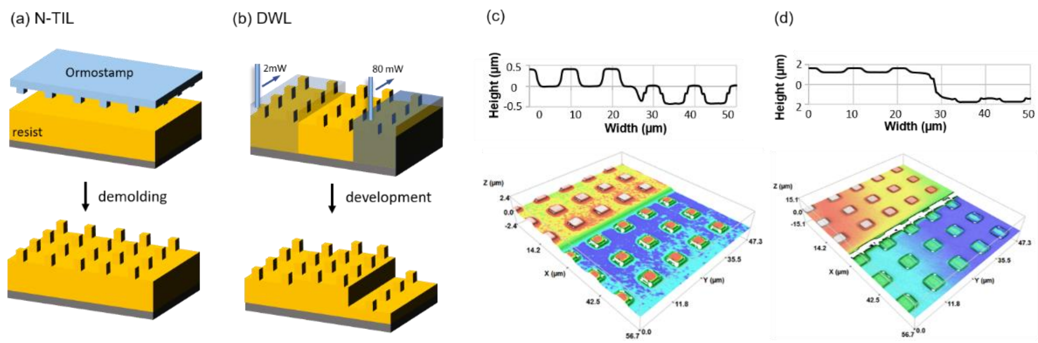

Figure 1: Fabrication process (a, b) and structure profile of the pre-imprinted ma-P1275G resist afer being exposed with DWL. The square pillars are imprinted by T-NIL at 120 °C, 2 MPa for 15 min (pitch 10 µm, height 430 nm). The exposure intensity in DWL is (c) 2 mW and (d) 80 mW, resulting in resist removal of ~417 nm and 2774 nm after 5 min development in AZ 726MIF, respectively. The pillar heights are 100% and 74% preserved, even after an isotropic development for 5 min.

Table 1: Results of different thermal processing temperatures before or after DWL and prior to development

Process	Prebake	T-NIL before DWL				Reflow after DWL
parameter	100~105°C	100°C	110°C	120°C	140°C	150°C
Result	solvent evaporation	Suitable for T-NIL (15 min)	Suitable for T-NIL (15 min)	Suitable for T-NIL (15 min), Reduced sensitivity	Loses sensitivity completely	Well above T_g for surface energy optimization

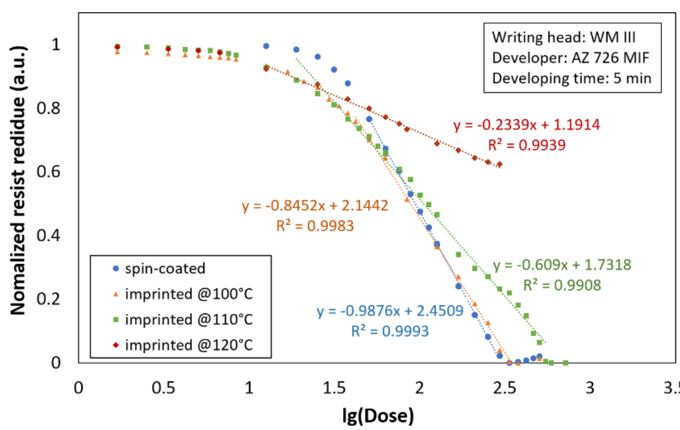

Figure 2: Contrast curve of mr-P1275G under different pre-exposure conditions.