Reflow minimization via viscosity control by exposure

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Hybrid lithography (combining UVL with thermal NIL) is an easy way to overcome the physical limitations of each lithography technique, the diffraction limit of UVL and the pattern density limit of NIL. An additional profit of this combined technique results from the use of conventional photoresists (negative and positive tone resists as well) and from the use of conventional non-transparent imprint-stamps. Earlier studies [1] have shown that two processing alternatives are possible: The conventional order hybrid lithography (1. nano-imprint, 2. photolithography, 3. development), and the reversed order hybrid lithography (1. photolithography, 2. nanoimprint, 3. development). These studies have shown that the reversed order hybrid lithography yields a better definition of the transition region between imprinted and lithographically defined patterns. However, alignment of the imprinted pattern with respect to lithography would require a transparent stamp. With the conventional order hybrid lithography the alignment is easy, since lithography is the second step. However, we found distinct standing wave effects primarily in the transition regime (Fig. 1).

In order to minimize standing wave effects in lithography common measures are: i) to use anti-reflective films, which makes the process more complex, ii) to use resists with high absorption or broadband sensitivity, which is not the method of choice for thin resists (see Fig. 2), and iii) to apply a post exposure bake (PEB), which is the most competitive one. However, with conventional order hybrid lithography such a PEB has to be performed in a well-controlled way [2] in order to minimize a reflow [3,4] of the already imprinted pattern.

Our goal is to perform hybrid lithography with alignment, which ultimately requires the conventional order process. Therefore this study focuses on the optimization of the PEB to minimize standing wave effects. As already shown in Fig.2, broadband illumination is unsatisfactory with the thin layers of interest here (≈ 300 nm). Also the use of temperature ramps (as common with cross-linking resists) is not profitable, as no trade-off between viscosity increase and reflow can be obtained without cross-linking. Instead, our idea is to make use of a different physical aspect, the specific change of the viscosity of a photoresist upon exposure due to i) a change in molecular weight (see Fig. 4 for a non-cross-linking, negative tone resist) or ii) a change in physical chain clustering (with positive tone resists), both resulting in a higher viscosity within the non-developing part of the patterns. We will show that an optimization is possible, as both effects involved, the diffusion of the photo active component and the viscous flow of the resist, obey different temperature relationships.

[1] K. Dhima et al, Microelectr. Engineering **100** (2012) 37-40.
[2] M. Wissen et al, Microelectr. Engineering **73-74** (2004) 184-187
[3] H. Schift et al, Microelectr. Engineering **88** (2011) 87-92.
[4] T. Leveder et al, Applied Physics Letters **92** (2008) 013107

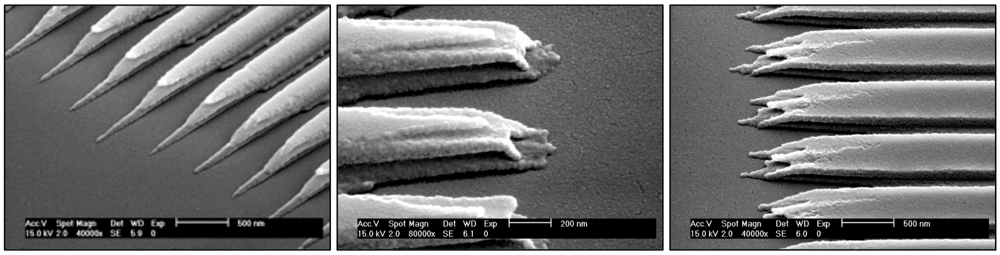

Figure 1: Standing wave effects along photo-mask edges as a result of conventional order hybrid lithography. The photoresist is ma-N 405. Imprint parameters: T = 100°C, p = 100 bar, t = 5 min; lithography: D = 350 mJ/cm^2, t_{entw} = 3 min

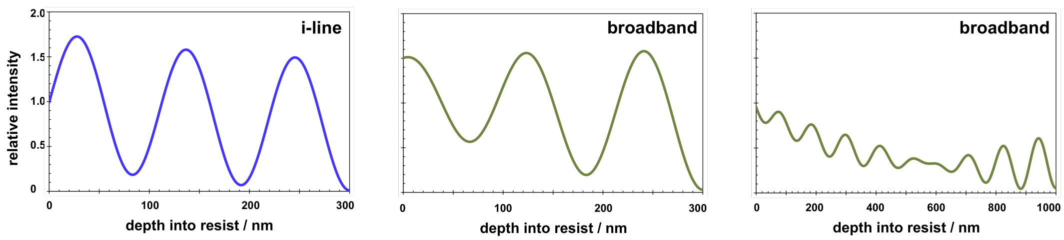

Figure 2: Relative intensity distribution within photo-resist layers of 300 nm and 1 µm (0 = surface) showing standing waves. For broadband illumination the Hg lines were summed-up (weighting: i: 40%, h: 28%, g: 32%). Similar sensitivity for all 3 lines was assumed. Absorption is considered with an absorption coefficient of 1.2 µm^{-1}.

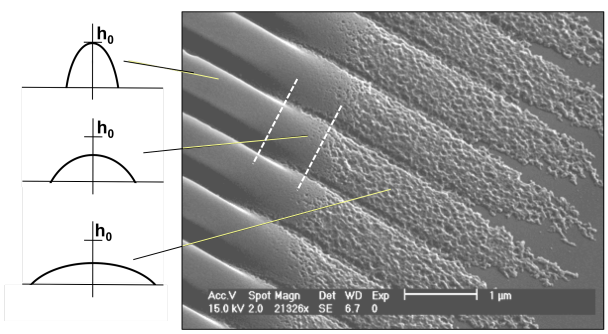

Figure 3: Detail of hybrid pattern near mask edge obtained with PEB (100°C) for avoidance of standing waves.
As the PEB is performed with a patterned layer (imprinted lines), reflow occurs. Differing grades of reflow develop locally, depending on the local exposure dose.

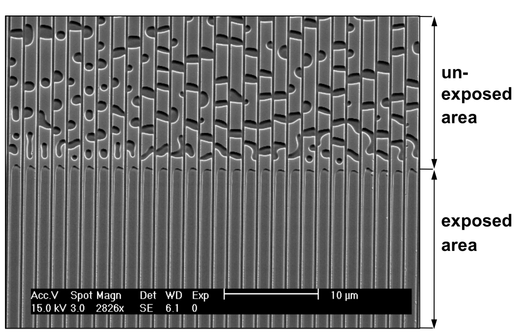

Figure 4: Imprint into a resist layer (ma-N 405) that was exposed through a mask prior to imprint.
The physical self-assembly (top) indicates a lower viscosity within the unexposed region. Obviously, the local exposure has increased the viscosity.