Functional vertical sidewalls and draft angles for easy demolding in the same mold in thick epoxy resist

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Vertical, straight sidewalls are essential in functional geometric elements for a range of applications, from cylinder microlenses, contact areas for gears and even for microfluidics, where precise channel widths are needed for valves or controlling flow, thus requiring processes than can produce high aspect ratio (HAR) structures. As the main processes for lithographic patterning, deep reactive ion etching and deep UV-lithography have been developed, and particular effort has been made to reduce any kind of non-perfect sidewall properties [1]. Now, vertical sidewalls are often detrimental, e.g., if the devices have to be produced with molding techniques. In the demolding process the mold has to be slowly retracted from the molded structure, and all (vertical) sidewalls undergo friction from the first point of detachment of all lateral walls up to the full release of the structure. Although undercuts and interlocking are often avoided as sidewall imperfections in the mold by careful optimization, even in perfect molds friction can cause deformation both in the molded structure and the mold when critical stress is exceeded or material is too weak [2]. In contrast to this, non-vertical sidewalls with positive inclination detach instantly. Therefore complicated geometries have always favored a defined so-called “draft angle” in the range of a few degrees. It would be an advantage if the vertical sidewalls would be avoided in areas of lower interest, e.g., in bends connecting straight sections in microfluidic devices or other features such as pillars that enhance the pattern density for easier molding. Unfortunately, current process technologies do not allow for precise tailoring of sidewall inclination and shape within a narrow range, presenting a challenge for device fabrication.

Direct write lithography (DWL) is a versatile maskless lithography tool that allows for cost-efficient fabrication of microstructures for a wide range of applications, including microelectronics, microfluidics, and photovoltaics [3]. The DWL 66^+ from Heidelberg Instruments Mikrotechnik GmbH (Heidelberg, Germany) offers several options for focusing at 405 nm (h-line) wavelength. We have found that DWL 66^+ can produce different sidewall angles depending on the write mode (WM) used, which are basically lenses with different focal lengths F and numerical apertures N_A (Table 1 and Figure 1). For systematic analysis, we exposed mr-DWL 40 from micro resist technology GmbH (a resist similar to SU-8 for h-line exposure) by varying localized dose with each WM, i.e., the variation of the dose according to the requirement of the structure [4]. However, such differences of sidewalls were not found in a consistent manner, instead, different WMs could be used. This hybrid mode, i.e., by manually changing the objective lens and realigning by optical pattern recognition is producing almost vertical sidewalls in areas of interest and sidewalls with a positive slope. After exposure, the resist is developed. We have found that for WM I sidewalls with positive slope (78°) and WM III for nearly vertical sidewalls (88°) can be achieved in 60 µm thick resist (Figure 2). Currently, these values are dependent on the thickness of the resist, and best results have been achieved for thickness <60 µm. We expect that in future processes, software such as GenISys Lab can be used to predict sidewall angles that would avoid many optimization runs.

[1] V.J. Cadarso et al., *High aspect ratio nanoimprint process chains*, Microsyst. & Nanoeng. 3, (2017) 17017.

[2] H. Schift, *Nanoimprint lithography and micro-embossing in LiGA technology: similarities and differences*, J. Microsystem Technologies 20 (2014) 1733-1781.

[3] V.J. Cadarso et al., *Direct writing laser of high aspect ratio epoxy microstructures*, J. Micromech. Microeng. 21 (2010) 017003.

[4] M.R. Haq and H. Schift, *Vertical sidewalls in thick epoxy resists – a challenge for laser-based direct write lithography*, Micro and Nano Eng., MNE_100210, accepted (22 May 2023).

Table 1. Parameters of the write modes (WM) I and III for the DWL 66^{+}.

Write mode, WM	Focus length, F	Numerical aperture, N_A	Writing speed
I	4 mm	0.8°	13 mm^2/min
III	10 mm	0.45°	160 mm^2/min

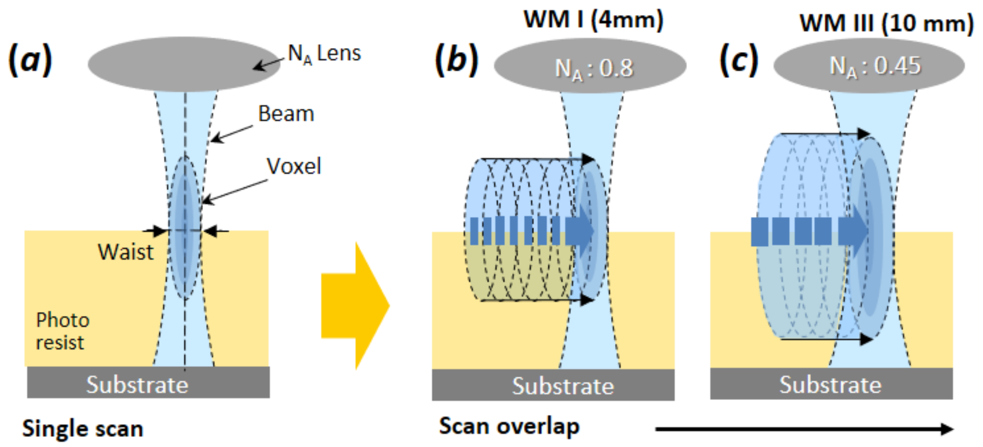

Figure 1. Schematics of WMs using focused light by direct laser writing. Different voxel sizes are generated with an intensity threshold that defines the interaction volume for initiating resist chemistry (for negative resists cross-linking). By varying dose, sidewall angles can be tailored to be vertical for WM III and with positive inclination for WM I.

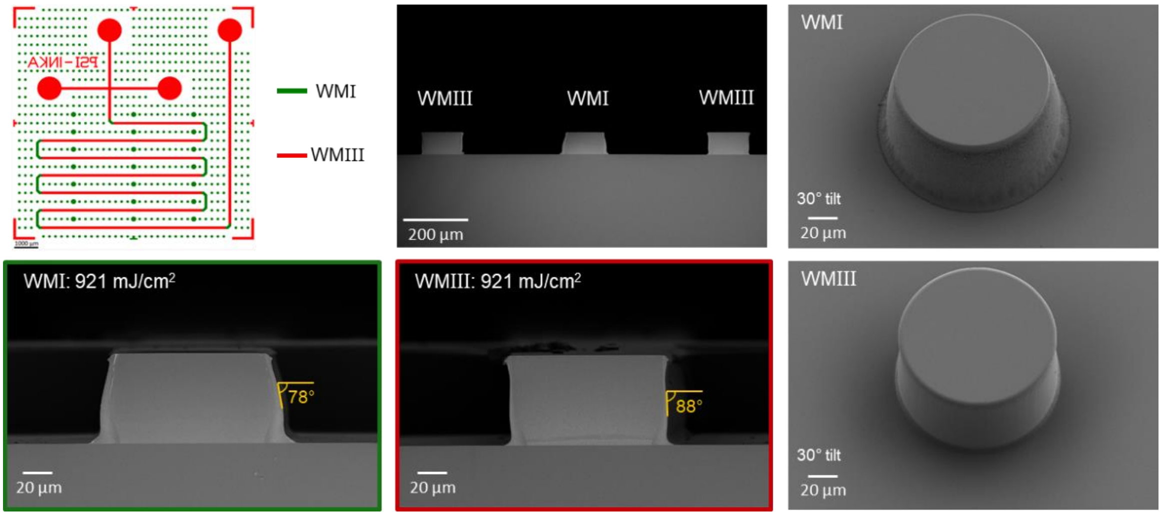

Figure 2. Design of the microfluidic structure exposure (10×10 mm^2) with the combination of different write modes (top-left). For microfluidic devices, only the straight sections need to have vertical sidewalls, but for other, auxiliary pillar structures and bends, draft angles would be favored. SEM micrographs of ~60 µm thick mr-DWL40 on Borofloat glass wafer using WM I for pillars and WM III for ridges (1st and 2nd column). Sidewall angles are given for the top half of the structure (undercuts are not considered). By changing WM between exposures, inclined and vertical sidewalls of pillars with a diameter of 100 µm can be combined in the same resist (3rd column).