Thin hard mask layers for high-resolution transfer in t-SPL enabled processes

M. Käppeli, J. Chaaban, N. Hendricks, E. Çağın
Heidelberg Instruments Nano AG, Bändliweg 30, 8048 Zürich, Switzerland
myriam.kaeppeli@himt.ch

Thermal scanning probe lithography (t-SPL) is a direct write lithography method where a heated tip is used to pattern a thermally sensitive resist or to directly modify a surface. This technique is used by the NanoFrazor tool of Heidelberg Instruments, which enables simultaneous structure patterning, reading, and on-the-fly correction. Over the years, a wide range of applications has been enabled by the NanoFrazor, from high-resolution lithography for nanoelectronic devices[1] to direct physical[2] and chemical[3] modification of materials. Some of these applications, such as the fabrication of quantum devices[4], benefit particularly from the high-resolution capabilities of the technique.

Along with the NanoFrazor tool, several pattern transfer processes have been developed, including high-resolution etching (HRE) and lift-off (HRLO) processes [Fig. 1]. These processes require a specialized multilayer transfer stack to enable the transfer of ultra-high-resolution features (10 s of nm). This high-resolution stack (HR stack) is composed of three main parts; the thermal resist (usually polyphtalaldehyde (PPA)), the hard mask layer, and an organic transfer layer. The function of the hard mask layer is to serve as an etch mask for the underlying thicker transfer layer while preserving the resolution of the patterned features. A high etching selectivity to the organic transfer layer and a minimal hard mask layer thickness (<10 nm) are therefore desirable.

The choice of hard mask material has a high impact on the final resulting structures. Parameters such as resolution, depth or height, and line edge roughness of the final features are dependent on the material and thickness of the hard mask layer. Considerations such as compatibility with direct laser sublimation (DLS), ease of use and availability of the materials must also be accounted for.

In this talk, I will present the different materials used and tested in our laboratory (spin-coatable oxides, evaporated oxides, etc.), as well as best practices for depositing and etching these hard mask materials. I will also present unique devices [Fig. 3] created using high-resolution transfer stacks with different hard mask materials.

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[1] A. Conde-Rubio *et al.* ACS Applied Materials & Interfaces **14** (37) (2022)
[2] X. Liu *et al.* Adv. Mater. 200123 (2020)
[3] S. Raghuraman *et al.* Nano Letters **17** (4), 2111-2117 (2017)
[4] L. Shani *et al.* Nanotechnology **35** 255302 (2024)

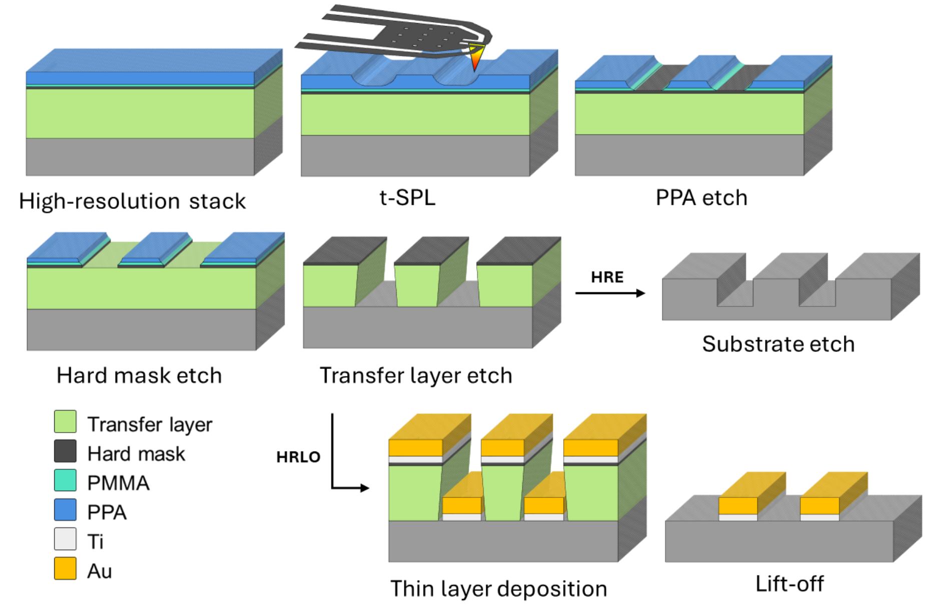

Figure 1: High-resolution transfer processes with the NanoFrazor: High-resolution etching (HRE) and high-resolution lift-off (HRLO).

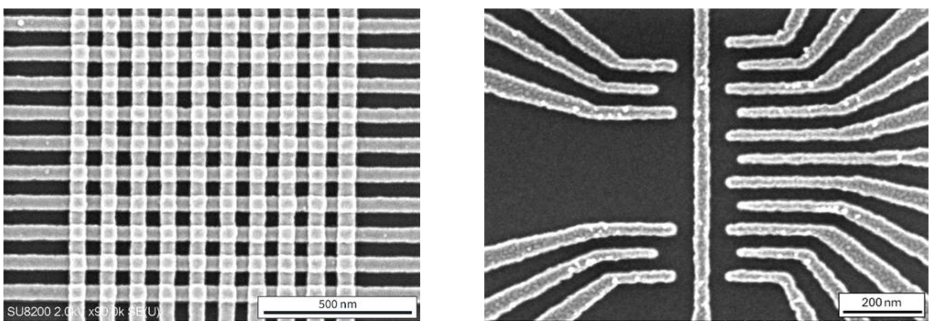

Figure 2: SEM images of metallic structures created with the NanoFrazor t-SPL tool and associated high-resolution lift-off process, using evaporated silicon oxide as the hard mask material. Left: Overlapping 50-nm-wide lines with minimal width broadening. Right: Electrodes with 30 nm critical dimension.

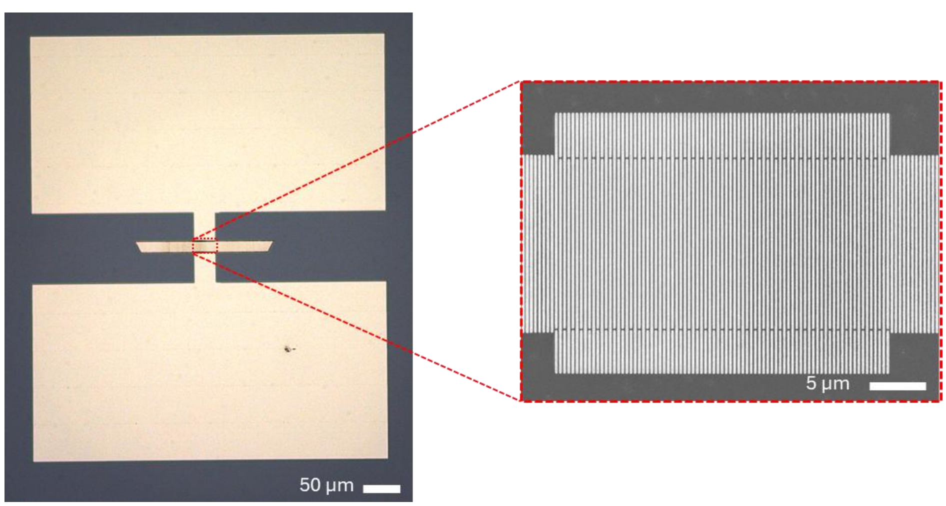

Figure 3: Optical (left) and SEM (right) images of a device with 180-nm-wide interdigitated electrodes, realized with the HRLO process using a spin-coatable silicon oxide as the hard mask layer.