High-performance spin-coatable hardmasks for transferring high-resolution t-SPL patterns

T. S. Kulmala*, S. Bisig, M. Spieser, U. Duerig, F. Holzner
SwissLitho AG, Technoparkstrasse 1, 8005 Zürich, Switzerland
**kulmala@swisslitho.com*

T. M. Gädda, K. Karaste, J. T. Rantala
PiBond Oy, Kutojantie 2, 02630 Espoo, Finland

As feature sizes of emerging device concepts in for example nanoelectronics and nanophotonics continuously shrink, a high demand for novel lithography and pattern transfer processes exists. Recently, thermal scanning probe lithography (t-SPL) [1] which relies on the thermal decomposition of polymer resists, such as polyphthalaldehyde (PPA) has entered the market. Using this technique, single-digit nanometer patterning and pattern transfer [2] as well as superior alignment accuracy [3] and sub-nanometer accurate 3D patterning [4-5] have been demonstrated. The patterning speed is comparable to high-resolution electron beam lithography [6].

As in all lithographic processes, patterning high-resolution features with t-SPL requires use of ultra-thin resist layers, posing challenges to subsequent pattern transfer processes. We have shown earlier that a few-nm-thick evaporated silicon dioxide (SiO_2) layer can be used as a hardmask to enable the transfer of PPA patterns into a layer of spin-on carbon [7] for further amplification of the shallow t-SPL patterns. However, evaporating thin and pin-hole free SiO_2 films requires dedicated tools and unnecessarily complicates the sample preparation process.

Here, we introduce a novel silicon-rich, spin-coatable hard mask that can replace the evaporated SiO_2 film in the pattern transfer stack. The hard mask can be spin-coated directly on common e-beam resists such as PMMA (for lift-off, Fig. 1a) or on a spin-on-carbon layer (for etching into the substrate, Fig. 1b). Continuous, pinhole-free films of the material are achieved with a thickness in the range of 2-3 nm making it ideally suited for high-resolution pattern transfer. Furthermore, the material is highly resistant to both oxygen and chlorine based reactive ion etching processes and a significant amplification of the original pattern depth can therefore be achieved. Here, we demonstrate high-resolution pattern transfer both via the metal lift-off (Figure 2) and substrate etching (Figure 3) approaches.

[1] Ricardo Garcia, *Nature Nanotechnology* **9**, 577-587 (2014).
[2] Y. K. R. Cho, *ACS Nano* **11** (2017).
[3] C. Rawlings et al., *ACS Nano* **9**, 6188 (2015).
[4] C. Rawlings et al., *Scientific Reports* **7**, 16502 (2017).
[5] T.S. Kulmala et al., *Proc. SPIE* **1058412** (2018).
[6] P. Paul et al., *Nanotechnology* **22,** 275306 (2011).
[7] H. Wolf, JVST B (2014).

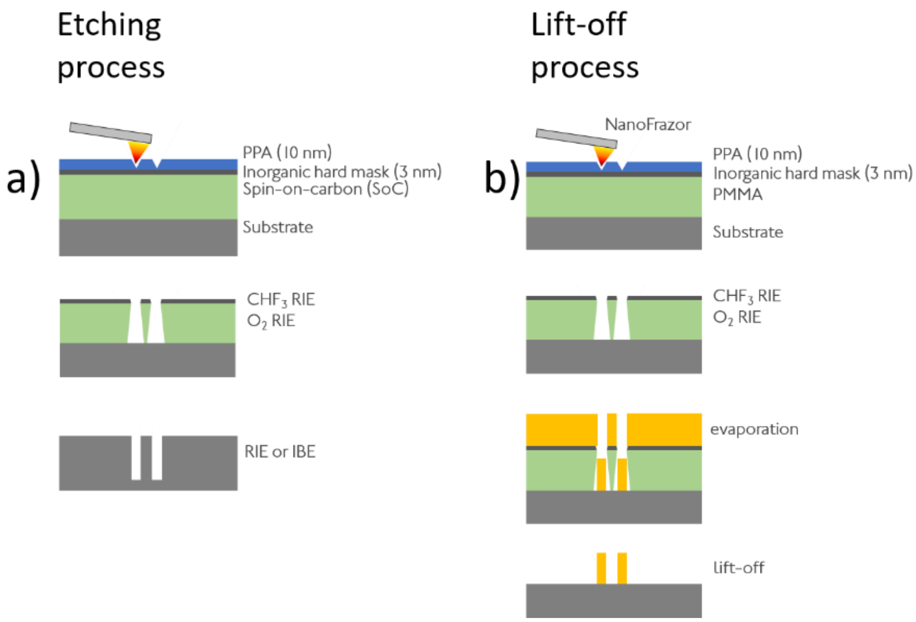

Figure 1: a) Process flow for etch transfer of t-SPL patterns into substrates. Spin-on-carbon layer improves the etching selectivity. b) Process flow for high-resolution metal lift-off. Here, the silicon-rich hard mask is spin-coated over a PMMA (or similar) layer that can easily be removed by a suitable solvent.

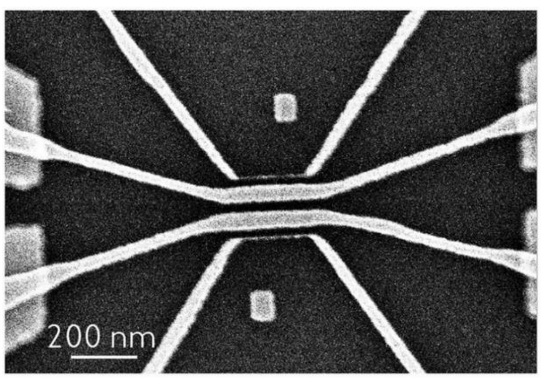

Figure 2: An example of a high-resolution metal electrode pattern fabricated by means of a lift-off process and a PMMA underlayer.

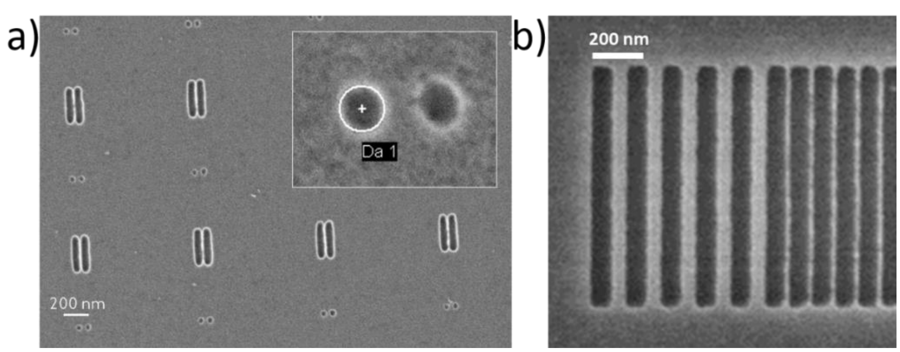

Figure 3: a) Line and dot pattern etched in 50-nm-thick chromium film by Cl_2 RIE. b) Line pattern etched 100 nm deep in Si by CHF_3/SF_6 RIE.