Mix&Match Electron Beam and Scanning Probe Lithography for sub-5 nm Patterning

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To maintain Moore's law in future, keeping the technological evolution alive on which our modern society is based on, novel nano-fabrication technologies acts as key enabler to open new horizons in nanotechnology and nanoelectronics.

An immense run is under way to get multiple-e-beam direct-write systems ready for high throughput manufacturing as possible successor for next generation lithography. However, patterning below 10 nm resolution and overlay alignment accuracy becomes an extremely challenging quest. Combining the benefits of EBL with the outstanding capabilities of closed-loop scanning proximal probe nanolithography (SPL)[1, 2, 3] reveals a promising way to improve significantly the patterning resolution and reproducibility in combination with excellent overlay and placement accuracy. Furthermore, the symbiosis between EBL & SPL expands the process window of EBL far beyond state-of-the-art.

In this paper we demonstrate proof of concept using the ultra-high resolution molecular glass resist calixarene. We used standard E-beam lithography system operating at 30keV and modified hybrid SPL-setup[4], wherein the generated electric field within the tip-resist gap causes a Fowler-Nordheim field emission current. This localized current flow is used for direct and/or indirect patterning of features into the molecular resist material. In conclusion, this approach allows the fabrication of chips in which all large features down to 20 nm are written by electron beam lithography (or EUV-Lithography) and all smaller features are written by SPL. Herein, we can apply SPL as pre- and post-patterning tool for EBL written features at critical dimension level. Furthermore, we can write using SPL after the EBL-exposure, before or after the development step. Thereby, pattern placement / alignment is realized by the SPL tool itself using either the latent EBL image which is detectable as sub-nanometer-steps at the exposed resist surface, or the developed resist structure after the wet development step.

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[1] Kaestner, M., Rangelow, I. W., "Scanning proximal probe lithography for sub-10 nm resolution on calix[4]resorcinarene", J. Vac. Sci. Technol. B 29, 06FD02 (2011).

[2] Kaestner, M., Rangelow, I. W., "Scanning Probe Lithography on Calixarene", Microelectron. Eng. 97, 96-99 (2012).

[3] Kaestner, M., Rangelow, I. W., "Multi-step Scanning Probe Lithography (SPL) on Calixarene with Overlay Alignment", Proc. SPIE – Int. Soc. Opt. Eng. 8323, 83231G - 9pp (2012).

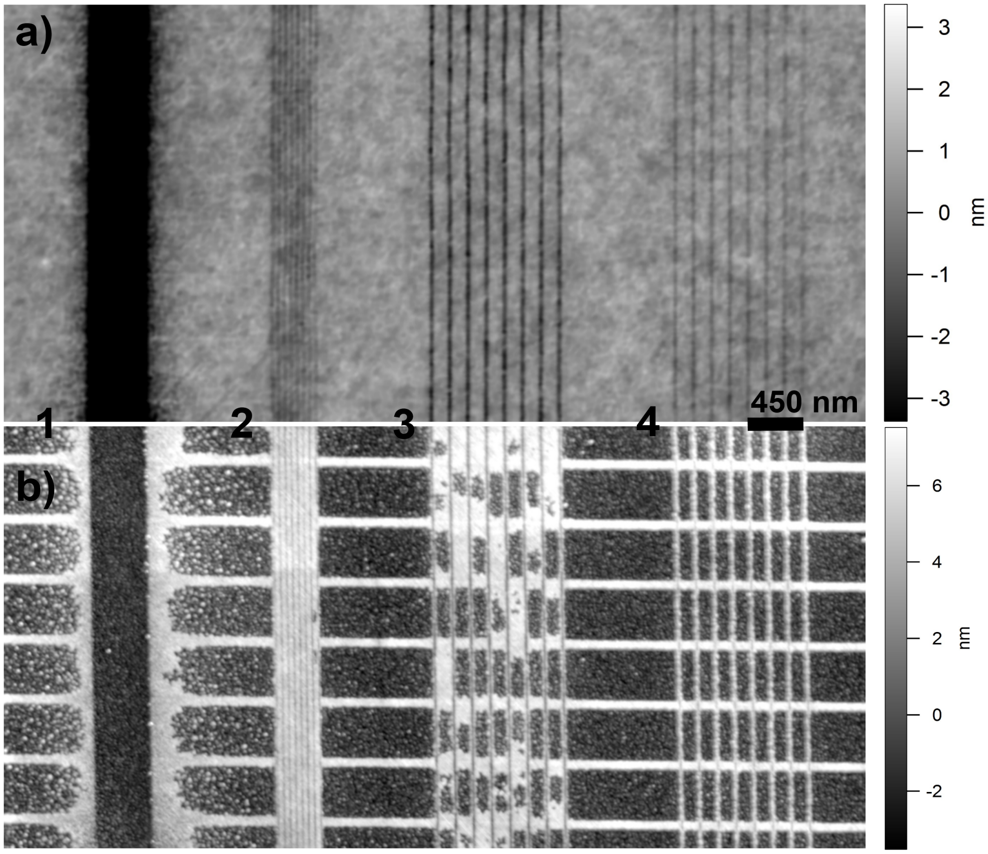

Figure 1: Demonstration of wide process window combining EBL (horizontal lines) and SPL (vertical lines): AFM images a) before and b) after wet development step showing: 1) Removal process; 2) & 3) Combination of removal and cross-linking process and 4) cross-linking process.

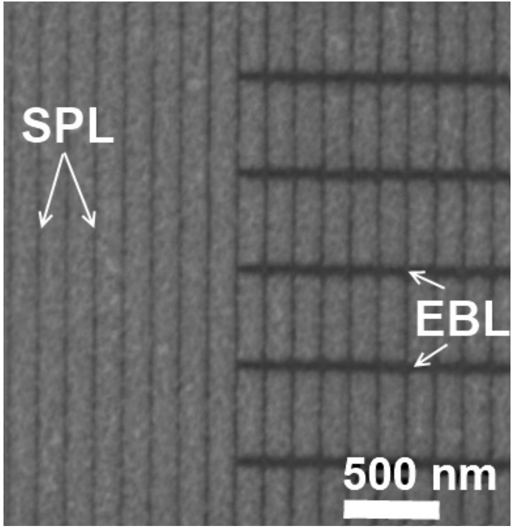

Figure 2: Demonstration of overlay alignment capabilities: SEM image after wet development showing alignment of SPL lines to EBL lines.

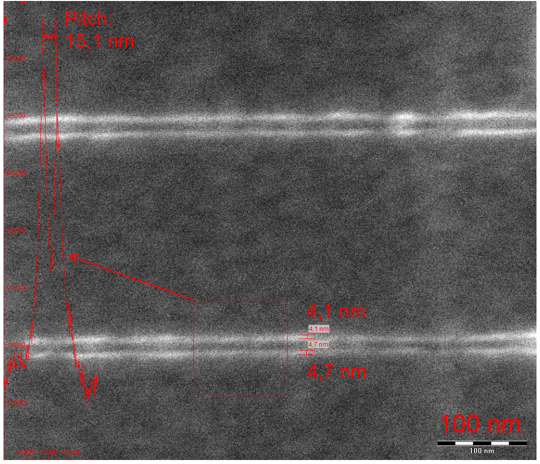

Figure 3: Demonstration of resolution capabilities: Patterning of lines with a half pitch of 7,5 nm and line width of less than 5 nm by SPL.