Quality Control of JEOL JBX-9500 E-beam Lithography System in a Multi-User Laboratory

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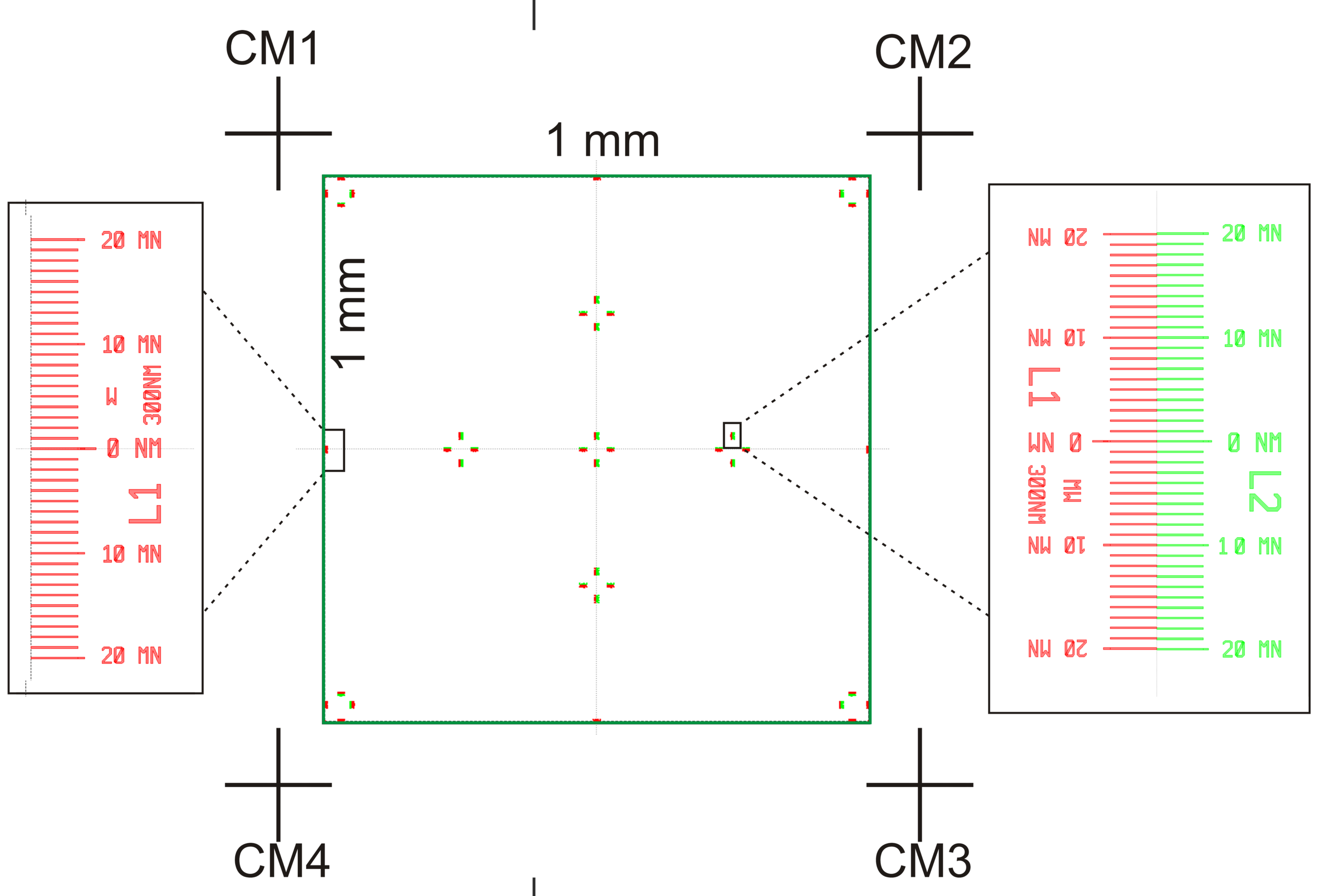
Consistent results pose a major challenge in multi-user open-access nanofabrication laboratories. Calibration can be done using special and dedicated instruments [1], however, this is time consuming and expensive. We address this challenge by a carefully designed quality control procedure on our JEOL JBX-9500 E-beam Lithography system.

We measure position accuracy, dynamical focus and astigmatism, as well as single and multi pixel lines in thin resist. We used the positive-tone semi-chemically amplified resist AR-P6200 (CSAR 62) from AllResist, which is considered to be an alternative to ZEP520A from ZEON [2].

JEOL JBX-9500 at DTU Danchip	
Acceleration voltage	100 keV
Beam currents	0.1 nA—60 nA
Beam Diameter	4 nm (@ 100 pA)
Writing field	1 mm x 1 mm
Max scan frequency	100 MHz
Substrate sizes	5—200 mm Ø
Stage position accuracy	0.5 nm
Cleanroom class	ISO 4
Temperature drift of room	0.05 K/h
Substrate load	10 cassette robot loader

Field stitching accuracy

Any type of position accuracy depends on positional drift due to temperature drift, vibrational noise, distortion of the beam in the main writing field, position and quality of alignment marks, and quality of substrate height measurement. When a pattern is larger than the main field size, the pattern will be stitched together by several fields. Between each field, the e-beam writer will move the stage one field size. The final pattern will contain errors where two fields are stitched together; these errors are assessed by exposing offset scales on the edges of several fields stitched together.



Field Stitching Accuracy

No FSW	X	$2.2 \pm 1.2\ nm$
	Y	$7.3 \pm 2.2\ nm$
With FSW	X	$0.5 \pm 1.3\ nm$
	Y	$2.8 \pm 1.5\ nm$

Field shift writing (FSW) is a technique where the pattern is exposed twice, and between each exposure the pattern is shifted with respect to the main field. Corners of the pattern are thus exposed with both centre and corner parts of the main deflector field; this smears out some field stitching errors.

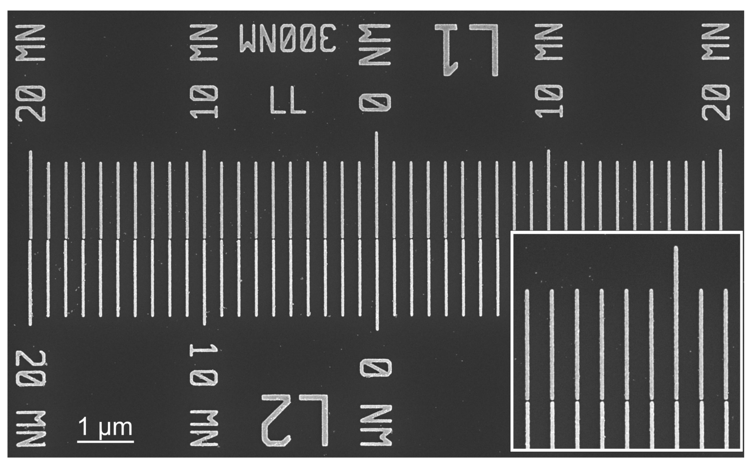
Overlay accuracy

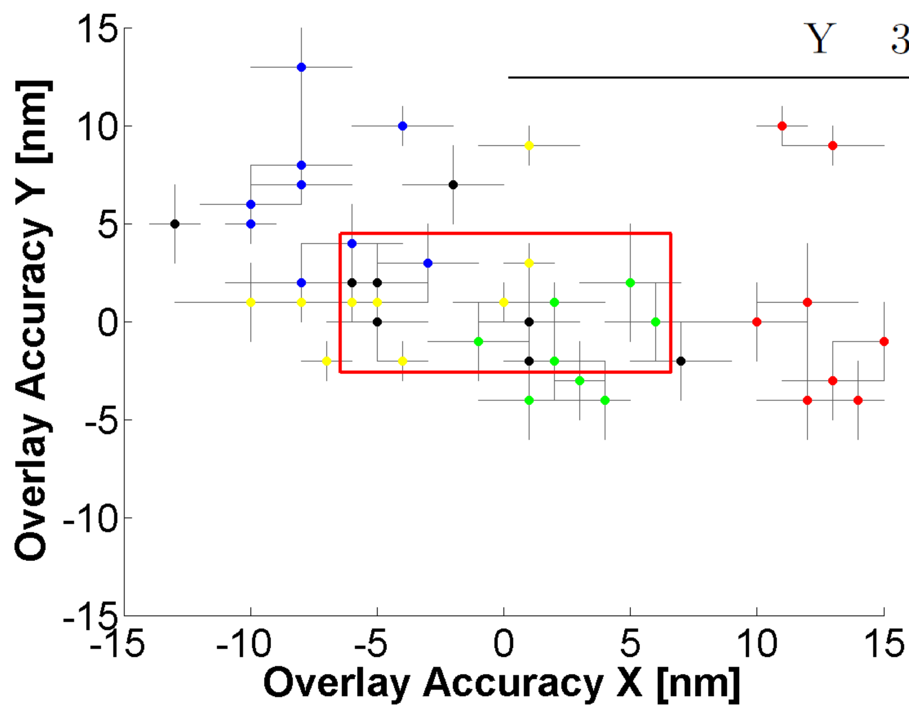
is important for multilayer writing that involves alignment to existing structures. Overlay accuracy is assessed by exposing two layers (red and green) in two seperate exposures, where each layer is aligned using global marks and chip marks on the wafer. These marks are defined by UV lithography, Cr/Au metallisation, and lift-off.

Before each exposure, the position of the 4 chip marks (CM1—CM4) are detected, and the displacement and size of the chip is corrected. After exposure of layer 1, the substrate is metallised, resist is lifted, and new e-beam resist is spin coated before exposure of layer 2, which is aligned using the same set of chip marks, but at a different scan position. The overlay accuracy is measured by the displacement in the 9 offset scales distributed over the main writing field.

Overlay Accuracy

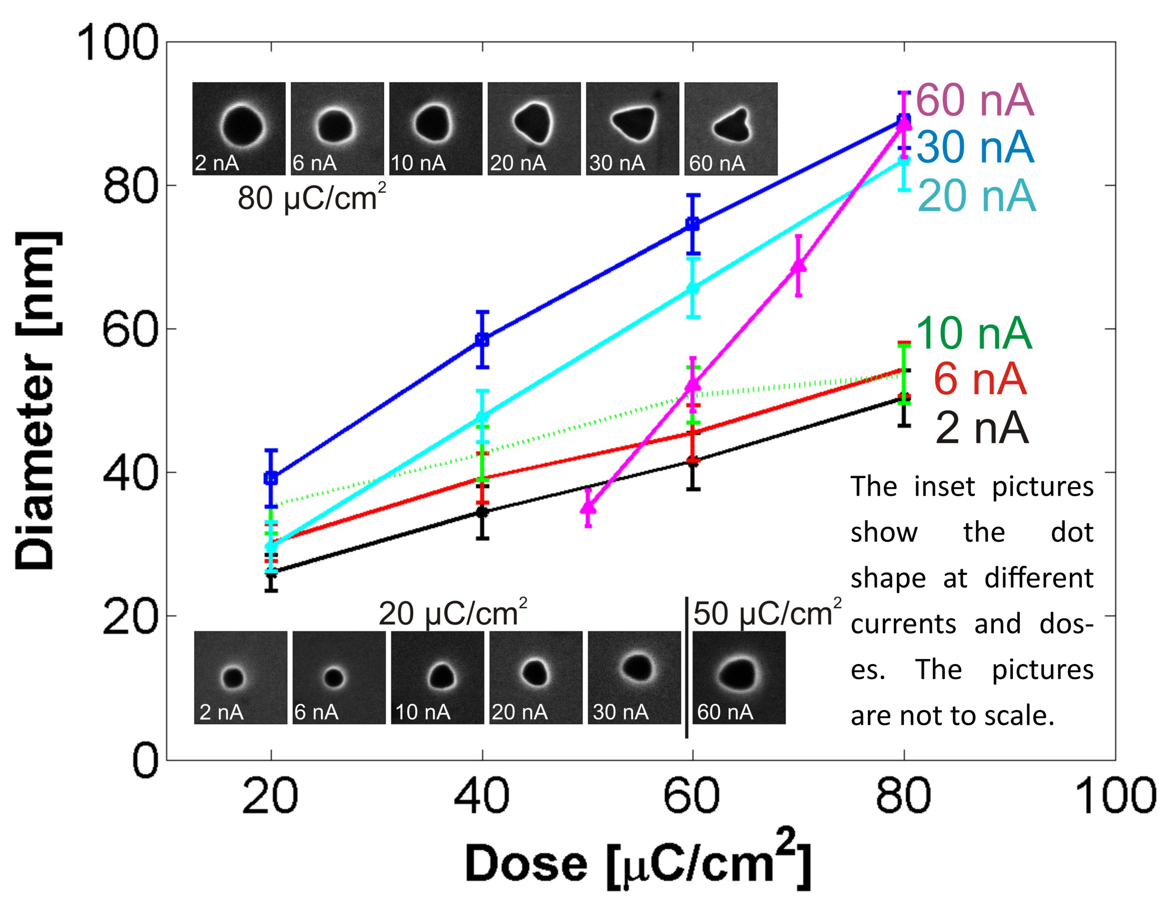
With FSW	X	$6.4 \pm 4.2\ nm$
	Y	$3.4 \pm 3.2\ nm$



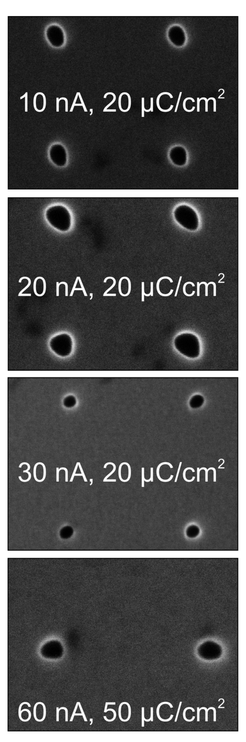


Dynamical focus (DF) and dynamical astigmatism (DS)

control ensures a homogeneous beam shape quality over the entire writing field. Without DF and DS, the beam will be out of focus and have elongated shape when deflected away from the centre of the field.



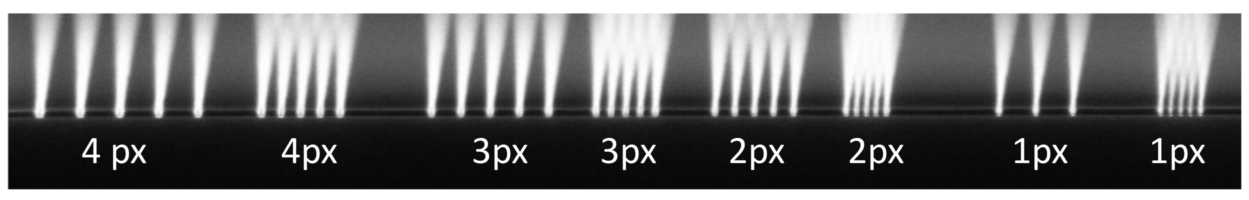
The inset pictures show the dot shape at different currents and doses. The pictures are not to scale.



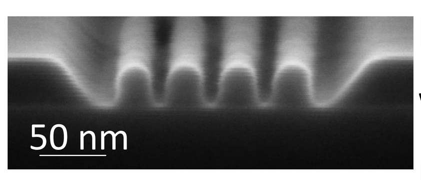
Dots in the corners. Pictures not to scale.

DF and DS is adjusted manually on a SEM test specimen. This procedure is not a part of the daily calibration routine; it is up to the process engineers to regularly check DF and DS at different beam currents. An efficient way to measure how well DF and DS work is to exposure dots on the fly [3]; this technique requires a precise DF and DS correction in order to yield uniform dot shape and size over the entire writing field. This method also gives us important information on beam diameter versus dose and beam current. We exposed entire writing fields of dots with a pitch of 200 nm at various currents and doses. After development, the patterns are transferred into the Si substrate using a shallow C_4F_8/SF_6 dry etch.

High resolution patterns



We test high resolution patterning by writing single and multi-pixel lines in approximately 50 nm thick resist. We do this to detect process inconsistencies. Under normal conditions we consistently pattern 12 nm lines.



Lines exposed with one beam shot in width (1 pixel lines) with a dose of 2200 µC/cm² and a beam current of 0.2 nA, developed in cold *AR-600-546*. The lines are ca. 12 nm in width. At doses below 2000 µC/cm², the lines were not fully developed.

Thanks to

JEOL for helpful and constructive conversations and instructions

[1] D. M. Tennant, R. Fullowan, H. Takemura, Y. Nakagawa, J. Vac. Sci. Technol. B **18**, (2000) 3089 – 3094

[2] S. Thoms, D. S Macintyre, Journal of Vacuum Science & Tecnhology B 32 (2014) 06FJ01

[3] E. Højlund-Nielsen, T. Greibe, N. A. Mortensen, A. Kristensen, Microelectronic Engineering 121 (2014) 104-107

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