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Greibe, Tine; Anhøj, Thomas Aarøe; Han, Anpan; Johansen, Leif

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

Tine Greibe , Thomas Aarøe Anhøj, Anpan Han, Leif S. Johansen

DTU Danchip, Technical University of Denmark, Kgs Lyngby, 2800, Denmark
e-mail: tigre@dtu.dk

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Consistent results are a major challenge in multi-user open-access nanofabrication laboratories. Calibration could be done using special and dedicated instruments [1], however, this is extremely time consuming and expensive. We address this challenge by a carefully designed quality control procedure.

Our 100 keV JBX-9500 e-beam lithography system is the newest Gaussian shaped e-beam writer from JEOL. It is designed for high throughput and high resolution patterning by combining a fast 100 MHz line scan frequency, high beam current ranging between 0.2 nA and100 nA, a writing field of 1 x 1 mm^2, and a robot loader for 10 cassettes. For cutting edge performance, the instrument is installed in a special constructed ISO 4 cleanroom, which is shielded from vibration and electromagnetic interference and has temperature drift control with an accuracy of 0.05 K/h (figure 1). The xy stage can position samples from 5 x 5 mm^2 up to 200 mm diameter wafers with an accuracy of 0.5 nm.

We have currently 25 users on this tool. To obtain consistent results it is vital to establish a quality control procedure to continuously detect possible inconsistencies and calibration issues. 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]. The resist is processed according to the manufacturer's guidelines. For high resolution patterning we used cold development at ~5 °C.

Our quality control procedure includes testing of pattern position accuracy, dynamic focus, dynamic astigmatism over the entire writing field, and high resolution writing. Overlay accuracy is important for multilayer writing that involves alignment to existing structures. It is measured to 5 ± 3 nm in X and 3 ± 2 nm in Y by exposing offset scales in both x and y directions in 2 different exposures where each exposure is aligned to the substrate by wafer marks and chip marks (figure 2). For patterning areas larger than the writing field, the stage must be moved and it is important that the patterns in adjacent writing fields are matched precisely. The field stitching accuracy in mask writing mode is measured to 5 ± 2 nm in X and 12 ± 3 nm in Y by exposing offset scales on the edges of adjacent fields stitched together.

For high through-put large area exposure, we use the single beam shot mode ('dots on the fly') technique which is a powerful method to pattern nanometer dot matrixes covering several cm^2 [3]. This technique requires a precise dynamical focus and astigmatism correction to supply uniform dot shape and size over the entire writing field. Using a beam current of 30 nA for high-throughput we pattern dot arrays over the entire writing field. For better imaging contrast, the single beam shot patterns are transferred into the underlying silicon substrate by a C_4F_8/SF_6-based reactive ion etch of ~50 nm. Even at a beam current of 30 nA, the dot diameter and shape can be controlled between 20 nm and 70 nm by dose control (figure 3).

Finally, we test high resolution patterning by writing single pixel lines and cold development. Under normal conditions we consistently pattern 12 nm lines (Figure 4).

In conclusion: When the JBX-9500 is thoroughly adjusted, we can minimize the field to field stitching to ~6 nm and ~13 nm in X and Y respectively and overlay accuracy to ~5 nm. Linewidths down to ~12 nm have been obtained in ~50 nm thick CSAR. Our quality control procedure ensures consistent high performance processes for our users, and preventive maintenance awareness for instrument engineers and laboratory management.

[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

Figure 1. JEOL JBX-9500 installed in our cleanroom facility at DTU Danchip. The room is an ISO 4 cleanroom and is screened from magnetic noise and temperature controlled with an accuracy down to 0.05 K/h.

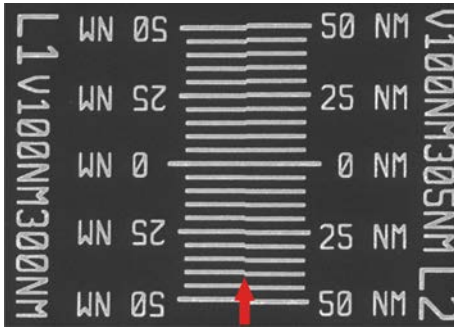

Figure 2. Measurement of overlay accuracy in y-direction using offset scales. The offset is 5 nm per line, i.e. these scales can detect shifts up to ± 50 nm in Y-direction. The offset here is < 5 nm.

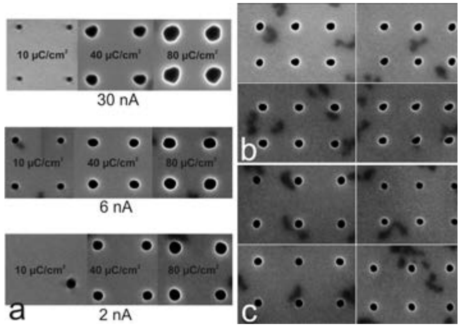

Figure 3. The exposed dots are patterned by single beam shots in ~50 nm CSAR 62 on a Si substrate and dry etched ~50 nm in the Si before SEM inspection. a) Dot shapes in the center of the writing field versus dose for 2, 6 and 30 nA beam current. b) Dots in the corners of the writing field of 30 nA exposed at 40 µC/cm^2, c) dots in the corners of the writing field of 2 nA exposed at 40 µC/cm^2

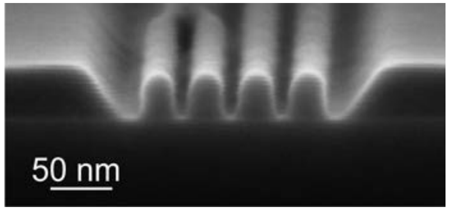

Figure 4. Profile of 1-pixel lines exposed in ~50 nm CSAR 62 with a dose of 2200 µC/cm^2. The linewidth is ~12 nm.