

# Results of Proof-of-Concept 50keV electron multi-beam Mask Exposure Tool (eMET POC)

Elmar Platzgummer<sup>\*</sup>, Christof Klein, and Hans Loeschner

IMS Nanofabrication AG  
Schreygasse 3, A-1020 Vienna, Austria

## ABSTRACT

First 50nm HP and 24nm iso line scanning stripe exposures with 1.4nm 1sigma stripe butting are shown of a proof-of-concept electron multi-beam Mask Exposure Tool (eMET POC), operating the column with an Aperture Plate System (APS), providing 256k (k=1024) programmable beams of 20nm beam size and 50keV beam energy at substrate within 82 $\mu$ m x 82 $\mu$ m beam array fields. Multi-beam proximity effect correction (PEC) is shown with long range corrections by local dose adjustments. The capability of exposing OPC jog patterns down to 1nm jog height is demonstrated as well as the possibility to expose complex ILT (inverse lithography techniques) patterns at no loss of throughput. The possibility to use low sensitive pCAR resist material with 80 $\mu$ C/cm<sup>2</sup> exposure dose is shown. The novel electron-optical column is suitable for Alpha, Beta and multi-generational HVM tools.

**Keywords:** mask writer, electron multi-beam technology, programmable multi-beams, electron beam projection optics.

## 1. INTRODUCTION

IMS Nanofabrication's multi-beam mask writer series is called eMET, which is short for electron Mask Exposure Tool. The basic principles common to all eMET systems are outlined in reference [1]. Mid 2011 a novel 200x reduction electron-optical column was realized as part of a proof-of-concept electron multi-beam Mask Exposure Tool (eMET POC). Initially the system was operated with a stencil plate to characterize the column performance. The experimental results were in agreement with simulated 5.3nm 1sigma blur within a beam array field of 82 $\mu$ m x 82 $\mu$ m at substrate [2]. End of 2011 first eMET POC exposure results were obtained with a programmable Aperture Plate System (APS), providing 256k (k=1024) programmable beams of 20nm beam size and 50keV beam energy. During these first eMET POC exposures with 256k-APS the laser-interferometer controlled stage was kept stationary [3]. The present paper concentrates on first eMET POC scanning stripe multi-beam exposures.

## 2. STATIONARY STAGE AND SCANNING STRIPE EXPOSURES

In stationary stage write mode the 82 $\mu$ m x 82 $\mu$ m beam array, consisting of 262,144 (512 x 512) programmable 50keV beams of 20nm beam size, is deflected in X and Y with the help of multipoles to fill up the space between the beams. This space is 160nm in X as well as in Y direction. In the scanning stripe write mode the 82 $\mu$ m x 82 $\mu$ m beam array is also deflected by  $\pm$  160nm while the substrate is moved at constant speed. Thus, exposure stripes of 82 $\mu$ m width were generated. Figure 1 shows exposure results obtained with the stationary stage write mode and with the scanning stripe write mode, respectively. There is no significant difference in resolution after having beam array X/Y scale and rotation adjusted, both of which are accomplished electronically, supported with in-situ diagnostics.

In both cases redundancy exposure techniques were realized by overlapping spots, reducing the impact of defective beams to tolerable levels [1, 4]. The 256k-APS used for the exposures had 28 "always-on" beam defects.

The max data rate of the realized 256k-APS is 12.8 Gbits/s [2]. With the eMET POC, however, continuous printing is limited to ca. 3.2 Gbits/s due to data download times into the stripe butters and the duty cycle of the POC stage.

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<sup>\*</sup> Elmar.Platzgummer@ims.co.at

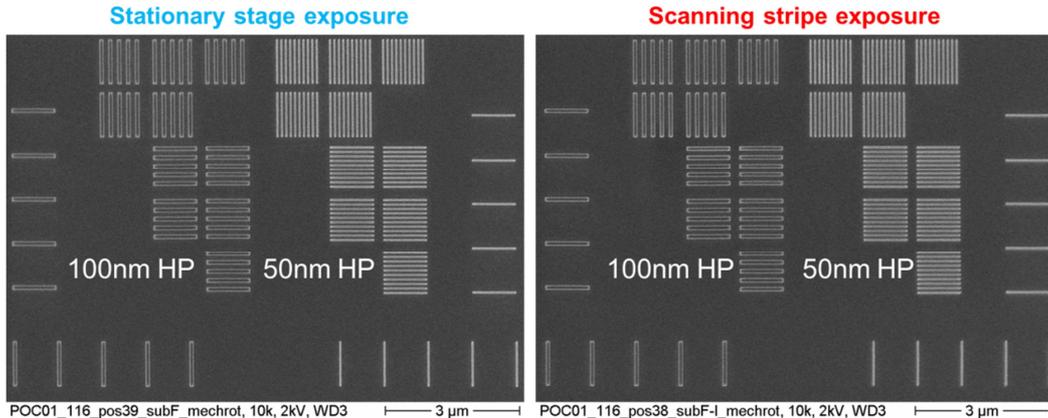


Figure 1: eMET POC operated with 256k-APS, providing 262,144 programmable beams (50keV beam energy, 20nm beam size, 0.1A/cm<sup>2</sup> current density) within 82μm x 82μm beam array field at substrate. Multi-beam exposure with 1200μC/cm<sup>2</sup> dose in 50nm HSQ negative non-CAR resist on 150mm Si monitor wafer. Left: Stationary stage exposure mode. Right: Scanning stripe exposure mode (0.1mm/s).

Stationary stage exposures of iso lines of 64nm to 24nm line width where shown to have ±0.5nm linearity (Figure 3, left [3]). Using a laser-interferometer controlled stage with 1nm 1sigma beam tracking precision, there is ±0.75nm linearity for scanning stripe exposure (Figure 2, right). The slight decrease of performance in scanning stage write mode can be understood by the limited degree of calibration for the first exposures. Eventually, the improved averaging makes the scanning stage write mode more robust and is expected to result in at least the same writing performance as in the stationary stage case. In both cases, no linearity corrections were done.

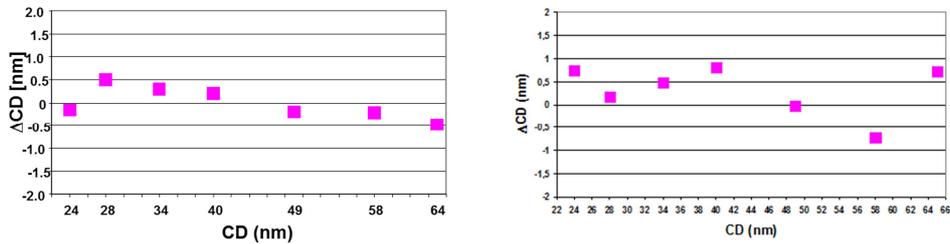


Figure 2: Iso line linearity in case of stationary stage exposures (left, [3]) and in case of scanning stripe exposures (right), using a 1nm 1sigma stage.

In Figure 3 (left) the stage scanning multi-beam exposure is shown of two stripes, each having 82μm width and 240μm length. There was 2μm overlap of the two stripes (Figure 4, right): The 100nm squares exposed in the overlap region with the left “Stripe 1” are indicated with the help of dotted oblique lines, and the 100nm squares exposed with the right “Stripe 2” are indicated with X/Y oriented dotted lines. From the difference of “Stripe 1” and “Stripe 2” center positions of the 100nm square matrix, the butting error of the two stripes was evaluated to be 1.4nm 1sigma.

Figure 3 (right) shows part of the Bossung pattern with oblique (45° and 135°) 50nm HP and single lines. Here, the exposure dose was varied in 10% steps from basedose - 20% up to basedose + 20% . There is 2.4nm change of line width with 10% change of dose which is in agreement with simulations. This dose latitude for scanning stripe exposure is the same as obtained for stationary stage exposures [2].

Improvement of the stripe butting error is in progress, implementing in-situ diagnostic and electronic adjustments of X/Y scale and rotation of the programmable 82μm x 82μm beam array field. Thus, fast optimization routines are possible as needed to achieve superior performance.

Detailed evaluations of the eMET POC patterning performance with respect to CDU etc. are in progress [5] of scanning stripe exposures in 50nm resist materials on 150mm Si monitor wafers as well as on Cr covered 6” mask blanks.

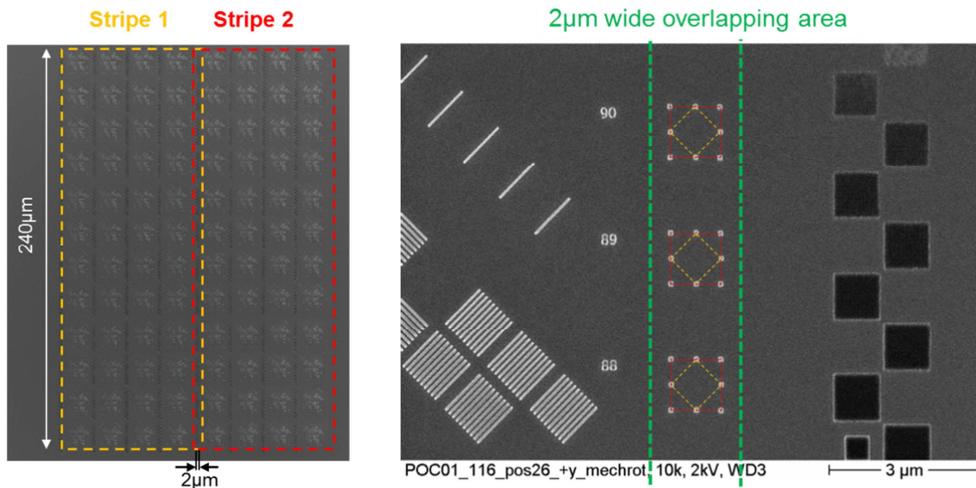


Figure 3: eMET POC scanning exposure of two stripes of 82  $\mu\text{m}$  width and 240  $\mu\text{m}$  length, with 2  $\mu\text{m}$  overlap between stripes.

### 3. SCANNING STRIPE EXPOSURE OF JOGS

With scanning stripe exposure, jogs of 25nm width and 100nm periodicity were exposed together with reference line without jogs. The jog height was varied from 10nm to 1nm. Figure 4 shows that jogs of 1nm height can be resolved in the scanning stripe mode (for a comparison with a result achieved in the stationary stage writing mode, see reference [3]).

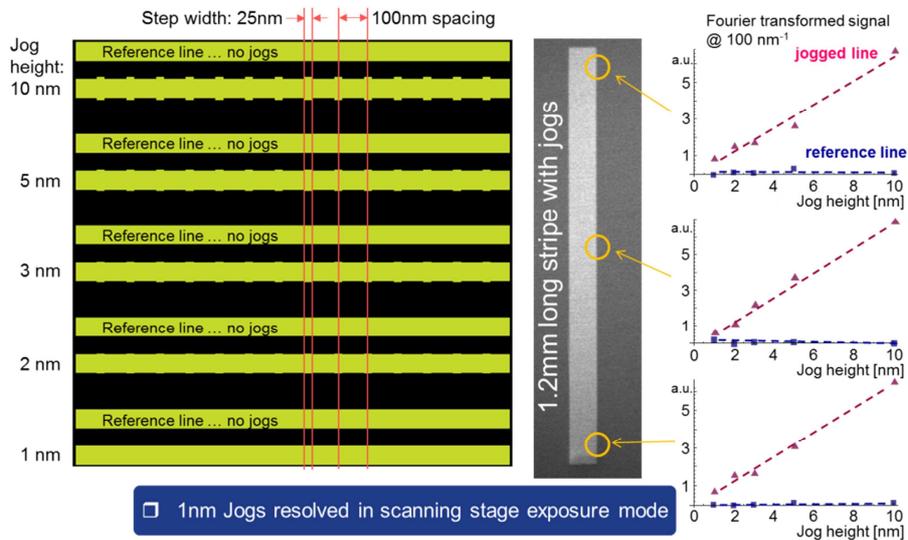


Figure 4: Scanning stripe exposure of jogs of 25nm width and 100nm periodicity with height between 10nm and 1nm. The Fourier transformed signal at  $100\text{nm}^{-1}$  shows that jogs down to 1nm height are resolved along a 1.2mm long strip.

### 4. MULTI-BEAM PROXIMITY EFFECT CORRECTION (PEC)

First exposures were done with multi-beam proximity effect correction (PEC), starting with long range corrections by local dose adjustments. Without PEC, 160nm lines were different by up to 42nm, depending if nested or embedded. With a preliminary (single iteration) PEC long range correction, this difference was lowered to 2.3nm within a  $82\mu\text{m} \times 82\mu\text{m}$

exposure field (Figure 5). Further improvement of CD accuracy down to < 1nm CD MTT is expected with improved PEC model parameters. The main conclusion to be made is that dose correction PEC can be applied using the gray level write strategy. In future, a combination of size and dose corrections will be implemented.

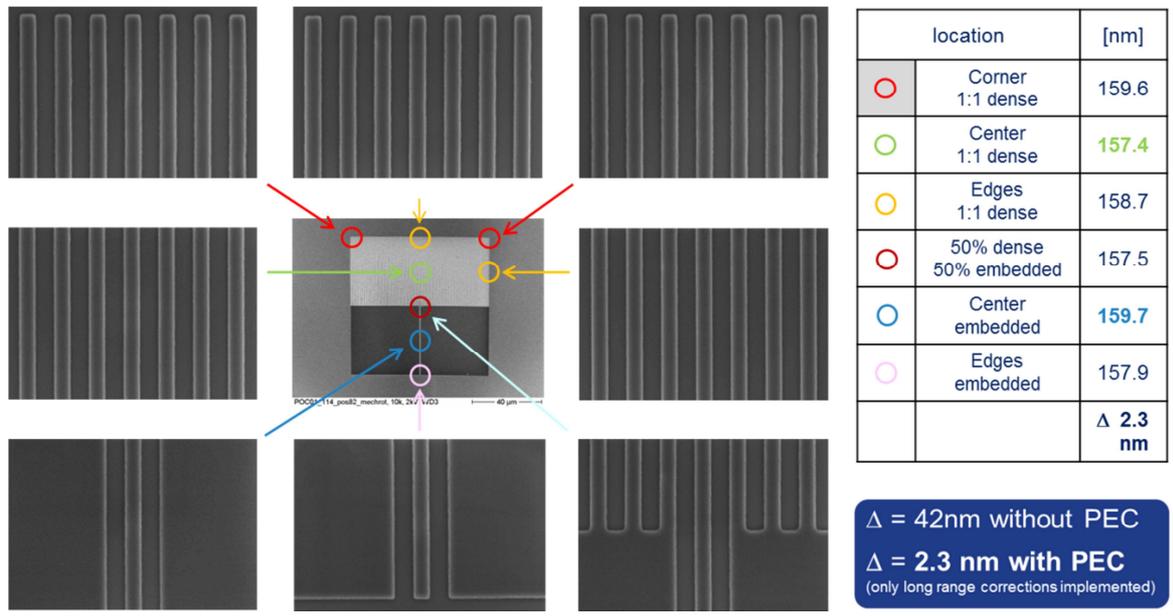


Figure 5: Multi-beam proximity effect correction (PEC), only long range corrections implemented.

For 50nm nested, isolated and embedded lines, there is a CD difference of 3.2nm (Figure 6), again only implementing long range corrections. Short range corrections will be added in a next step, in particular for patterns smaller than 100nm. With eMET, short range corrections can be implemented by sizing adjustments on the 0.1nm address grid (assuming 20nm beam size and 5nm physical grid), without loss of throughput. This is an important advantage of the eMET multi-beam writing techniques.

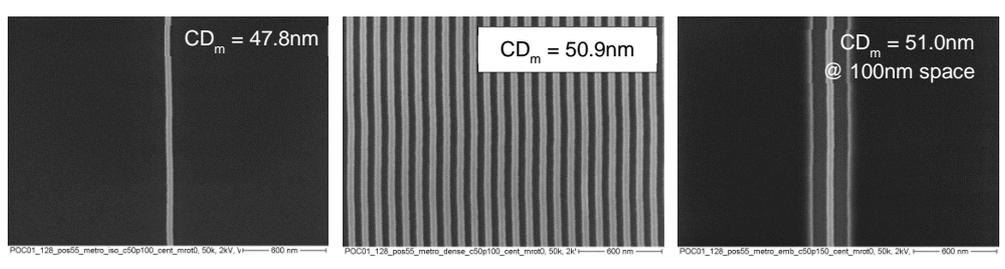


Figure 6: Multi-Beam PEC with long range corrections only of 50nm iso, nested and embedded lines (Remark: the line waviness is an artifact of the review SEM used).

### 5. MULTI-BEAM EXPOSURE OF ILT TEST PATTERNS

Inverse lithography techniques (ILT) are becoming mandatory for sub-20nm 193nm immersion lithography. With eMET multi-beam writing techniques, such complex patterns can be exposed without loss of throughput.

Scanning stripe exposures of ILT test patterns are shown in Figure 7. The design (courtesy DNP) contains smallest lines of 60nm width and dots of ca. 55nm diameter (there is deviation from circularity in the design). The exposure in HSQ negative non-CAR is in agreement with the design contours.

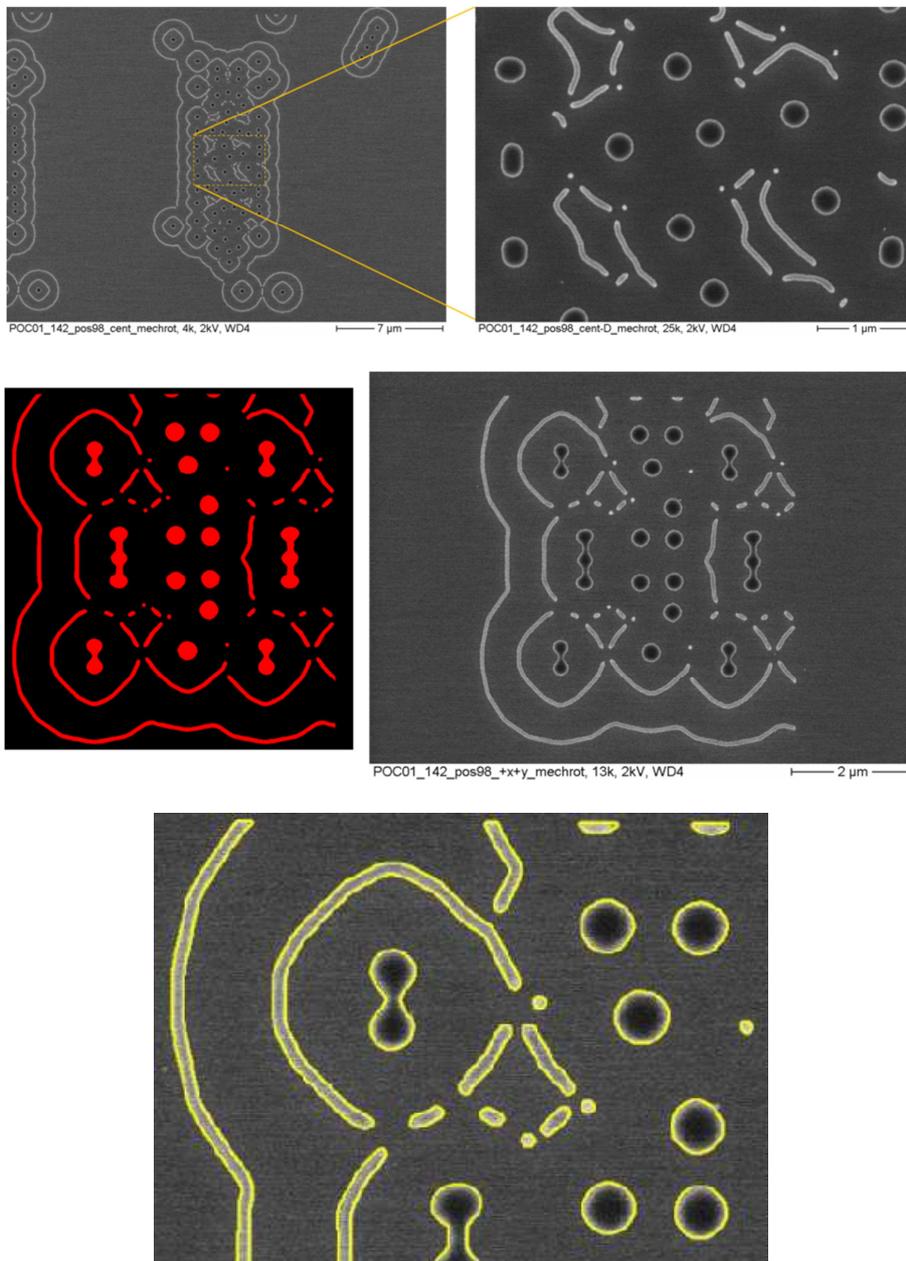


Figure 7: eMET POC scanning stripe exposures of ILT device test patterns (design: DNP).

## 6. SCANNING STRIPE EXPOSURE RESULTS IN LOW SENSITIVE pCAR

First exposures were done in 50nm low sensitive pCAR resist on 150mm Si monitor wafers (Figure 8). The exposure dose was  $80\mu\text{C}/\text{cm}^2$ . The stage velocity was 1mm/s.

In order to allow the exposure of pCAR with  $80\mu\text{C}/\text{cm}^2$  exposure dose, the brightness of the electron source was lowered to achieve  $0.1\text{A}/\text{cm}^2$  current density at substrate level. In order to do scanning stripe exposures in HSQ resist with  $1\text{mm}/\text{s}$  stage velocity the current density will be enhanced to  $1\text{A}/\text{cm}^2$ . Thus, the max overall beam current with all 262,144 beams (20nm beam size) through the column will be enhanced to  $1\mu\text{A}$ .

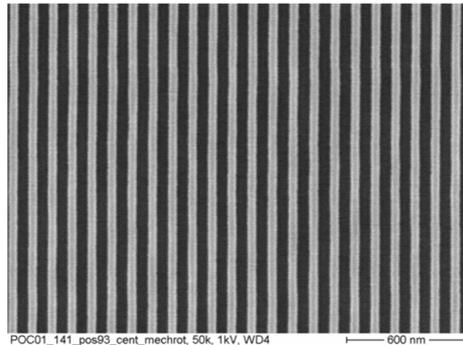


Figure 8: Scanning stripe exposure (stage:  $1\text{mm}/\text{s}$ ) of 50nm HP patterns in 50nm pCAR on 150mm Si monitor wafer. Exposure dose:  $80\mu\text{C}/\text{cm}^2$ . Multi-beam PEC was done with long range corrections only, resulting in a larger width of the iso-line.

## 7. SUMMARY

The status of the eMET multi-beam mask writer development can be summarized as follows:

Writing with 256k beams ( $k=1024$ ) on scanning stage (up to  $1\text{mm}/\text{s}$ ) shown. Multi-beam Proximity Effect Correction based on dose correction using gray level writing demonstrated. Prints on low sensitivity pCAR ( $80\mu\text{C}/\text{cm}^2$ ) confirm TPT capability. The novel electron-optical column worked reproducible and stable – suitable for Alpha, Beta and multi-generational HVM tools

## ACKNOWLEDGEMENTS

The 256k-APS, inserted to the eMET POC, consists of an Aperture Plate, fabricated by the Institute for Microelectronics Stuttgart (IMS Chips), and of a Blanking Plate with integrated CMOS electronics, where MEMS post processing was done by the Fraunhofer Institute for Silicon Technology (ISIT). pCAR coated substrates were provided by IMS Chips. Thanks are due to DNP for making available the design of ILT device test patterns.

## REFERENCES

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