Investigation of local registration performance of IMS Nanofabrication's Multi-Beam Mask Writer

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ABSTRACT

Reticles for manufacturing upcoming 10nm and 7nm Logic devices will become very complex, no matter whether 193nm water immersion lithography will continue as main stream production path or EUV lithography will be able to take over volume production of critical layers for the 7nm node. The economic manufacturing of future masks for 193i, EUV and imprint lithography with further increasing complexity drives the need for multi-beam mask writing as this technology can overcome the influence of complexity on write time of today's common variable shape beam writers. Local registration of the multi-beam array is a critical component which greatly differs from variable shape beam systems. In this paper we would like to present the local registration performance of the IMS Multi-Beam Mask Writer system and the metrology tools that enable the characterization optimization.

Key words:
Multi-beam mask writer, electron, MBMW, mask registration, mask metrology, pattern placement, optical lithography extension, proximity correction, model-based, LMS IPRO

1. INTRODUCTION

As design rules continuously shrink, reducing total wafer overlay error is one key factor to achieve and maintain high yields in wafer production. In addition to the various error contributions from the wafer scanner, the reticles used for the lithographic process contribute errors as well. Accurate placement of the features on reticles with a registration error below 2nm is mandatory to keep overall photomask contributions to overlay of 10nm or 7nm devices within the allowed error budget.

Only very careful adjustment of the EB mask writer ensures to meet the overall registration specification for the mask. Previous investigations [1] on the current EB writer generation revealed registration contributions on various spatial frequencies which have different error drivers. The global error is minimized by optimizing the X/Y-stage correction of the EB writer whereas the local registration error is induced by the electron beam stability and adjustment. Figure 1 demonstrates that the local registration can significantly contribute to the overall mask registration performance.

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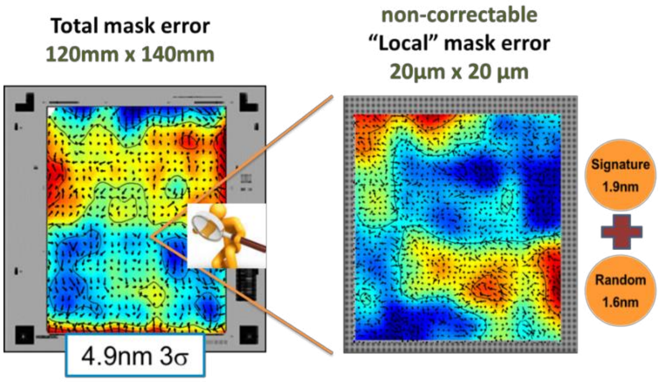


Fig.1: Total mask registration error (left) and the local contribution from EB adjustment and noise [1]

2. REGISTRATION CONTROL OF MULTI-BEAM MASK WRITER

The IMS Multi-Beam Mask Writers (MBMW) expose with 262,144 programmable 20nm-sized parallel beams [2]. With this novel pixel-based exposure strategy, throughput is completely independent of pattern complexity. But, for the MBMW to be a viable throughput solution, the system must be capable of meeting all the requirements of the future nodes. The specification of concern with multi-beam mask writers is registration.

Global registration has been well characterized by the industry. The mask writer's largest contribution is from the system's stage. Both VSB and Multi-Beam mask writers use sophisticated stage control systems and corrections to minimize the global registration error. IMS has partnered with JEOL, for the MBMW stage, who provides a novel platform with an air-bearing vacuum stage [3].

On the other hand, the local registration components from the VSB and Multi-Beam systems greatly differ. In a VSB system, each and every feature is stitched together using a single shaped beam. The local registration depends on the stability of the size and placement of this single beam. In contrast, the IMS multi-beam system exposes the features with an 82µm x 82µm array of 262,144 fixed size beams. The added complexity of the beam array requires an advanced set of diagnostic tools and adjustment scripts that are used to monitor and tune the local registration.

The MBMW system consists of an electron beam which is projected onto an aperture plate, forming the array of beams. A set of static lenses aligns the beam array along the column while the beam is accelerated and de-magnified 200X. Finally, the array is positioned onto the substrate with a beam steering multipole as shown in figure 2 [2, 4]. All these individual components must be tuned together to ensure the beam array has the correct scale, rotation, landing angle and position on the mask.

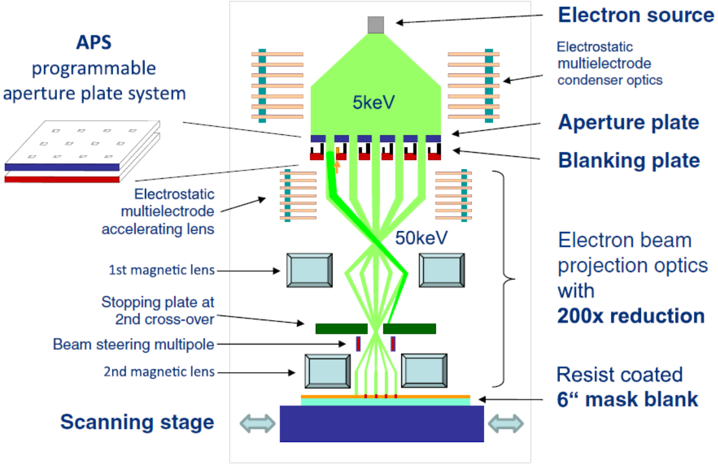


Fig.2: MBMW Principles [2, 4]

To fully characterize the local placement accuracy of all the individual beams in the array, a system of in-situ calibrations and test exposures is used. In order to perform such adjustments and verify the results on the mask, a large number of features must be measured. Previous generations of registration metrology tools are not well suited to perform this task as they are either not accurate enough or too slow.

3. METROLOGY DILEMMA AND ITS SOLUTION

Registration metrology tools take images from the reticle in DUV light to measure the actual device pattern position. For the evaluation of local registration error a small area on the mask is measured, typically smaller than 100µm by 100µm. The typical field of view of the metrology system has length and width of ~20µm and a large amount of small measurement targets fit into this area. All targets in the field of view could be measured simultaneously, however, remaining optical aberrations of previous generation metrology systems induce additional systematic measurement error >~0.5nm (figure 3). This amount of error is no longer negligible when determining local ebeam registration error less than 2nm. In order to avoid this additional metrology error, a potential mitigation strategy is to move each measurement target into the same location of the field of view restricting the measurement to one feature per field of view. However, the cost of this metrology strategy is a severe throughput hit, e.g. measuring a total amount of 19,600 targets takes about 40 hours and thus is not feasible to be performed on a frequent base.

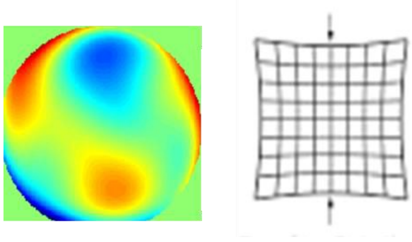


Fig. 3: Residual optical distortions (potential examples) prevent from accurate simultaneous measurement in the field of view for previous metrology tool generations.

The solution for the above metrology dilemma comes with the new LMS IPRO6 from KLA-Tencor including new measurement capabilities to enable accurate on-device registration measurement including the correction of optical aberrations. The LMS IPRO6 enables measuring all contacts in a field simultaneously with a residual error acceptable to evaluate EB registration errors smaller than 2nm. Figure 4 describes the model-based measurement flow which was reported in more details in a previous paper [5].

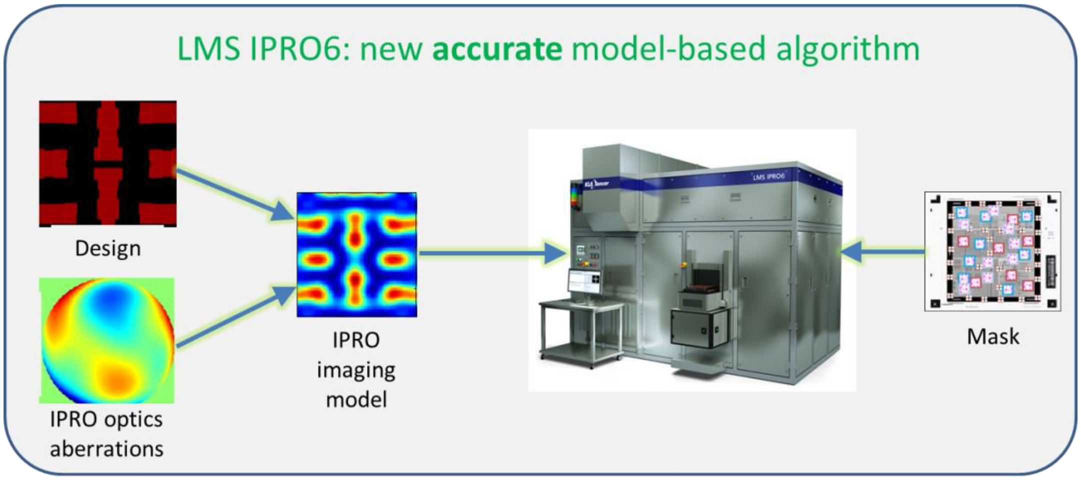


Fig. 4: The new accurate model-based algorithm of the LMS IPRO6 enables accurate on-device measurement including corrections for metrology tool optics aberrations

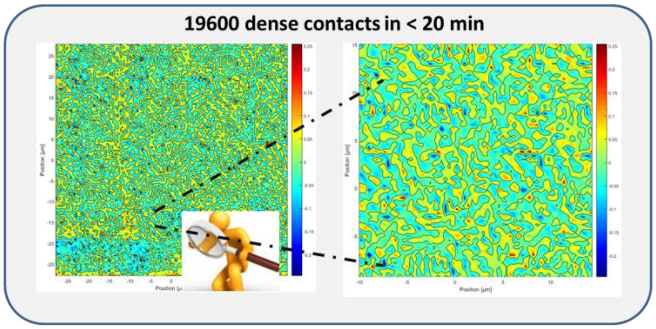
4. EXPERIMENTAL SETUP

The purpose of the study was to quantify the IMS MBMW's local registration capability of production type features with typical sizes. The test layout consists of a 56µm x 56µm dense array of 200nm contacts laid out on a 400nm pitch, totaling 19,600 features. The features were exposed on standard production 6% chrome/MoSi blanks coated with a low sensitivity PCAR photoresist (exposure dose of > 100 µC/cm^2). The masks were exposed and developed at IMS Nanofabrication, Brunn am Gebirge, Austria, and etched at the Institute for Microelectronics Stuttgart (IMS Chips) in Germany. The registration measurements were performed on KLA-Tencor's LMS IPRO6 R&D system in Weilburg, Germany.

The test consisted of two test masks exposed with varying states of beam calibration. The goals of the experiment include determining the viability and accuracy of the IPRO6 to measure the local registration, quantify the local registration of the MBMW tool at the two phases of calibration, and demonstrate the effectiveness of the current beam calibration techniques utilized by IMS Nanofabrication.

5. MEASUREMENT RESULTS AND MBMW LOCAL REGISTRATION PERFORMANCE

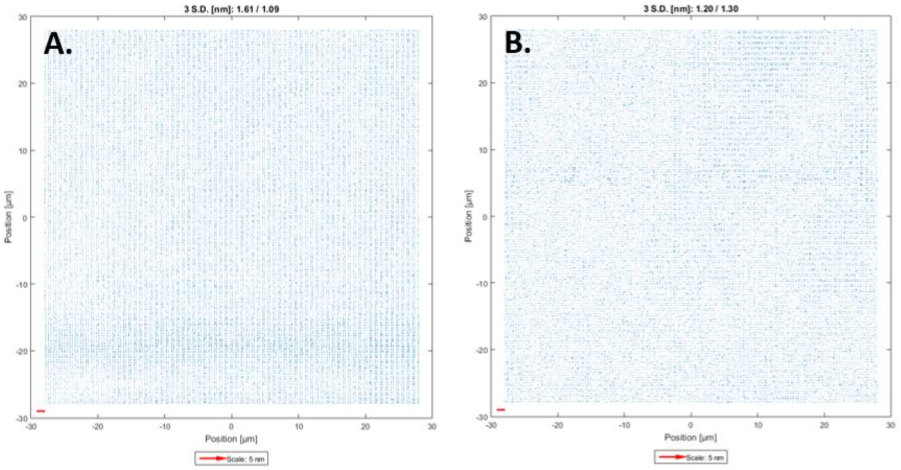
First step of the local registration evaluation was a simple experiment to verify the residual error of the metrology tool. Therefore the total array of 19600 contacts was measured twice and the mask was rotated 90 degree in between the measurement runs. Data acquisition took less than 20 min in both cases. The data of the "90-degree" measurement were back rotated to 0 degree by software and then compared to the "0-degree" data in registration mode. The 3 sigma values of the 0-90 degree accuracy were at maximum 0.23nm. This demonstrates that the LMS IPRO6 metrology tool provides sufficient accuracy to verify local registration error of an EB system able to support ITRS [6] registration specifications for 2016 and beyond (figure 5).



ITRS spec for 2016	Metrology Performance Accuracy: 0 – 90 degree / 3 σ		Acquisition time 19,600 contacts
Reg. [nm]	X [nm]	Y [nm]	[minutes]
1.8	0.19	0.23	< 20

Fig. 5: Actual measurement performance for local registration on the LMS IPRO6.

Second, the two plates were measured in the "0-degree" orientation and analyzed using the same measurement strategy as to quantify the metrology accuracy. The results show that prior to the optimization, there is a slight registration error at the bottom of the array. After careful calibration, the local registration is clearly improved with the final performance of a maximum 3 sigma error of 1.3nm (figure 6). The results validate the calibration techniques and demonstrate the MBMW tool's ability to greatly exceed its local registration specification of 5.0nm 3 sigma. Furthermore, the current performance enables achieving the ITRS [6] registration specification for 2016 and beyond.



	A.) Pre-Optimization		B.) Post-Optimization	
Registration 3 σ	X [nm]	Y [nm]	X [nm]	Y [nm]
	1.61	**1.09**	**1.20**	**1.30**

Fig. 6: Actual local registration performance of the IMS MBMW at various stages of calibration
A.) Pre-optimization B.) Post-optimization

6. CONCLUSION

It was verified that the registration metrology dilemma was solved and KLA-Tencor's LMS IPRO6 enables both, fast and accurate local measurements, to verify local registration performance of the most advanced ebeam writer systems. The measurement accuracy (measured 0 versus 90 degree mask orientation) is below 0.25nm (3 sigma) and 19600 contact measurements were accomplished within less than 20min. This fast and accurate metrology capability enables the detailed investigation of the local registration of the IMS MBMW beam array.

The local registration results of the MBMW system were found to be below 1.5nm (3 sigma) when fully optimized. The data set demonstrated that the existing calibration techniques and tools used by IMS Nanofabrication today are effective in meeting the local registration needs of 2016 and beyond.

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