MBMW-101: World's 1st High-Throughput Multi-Beam Mask Writer

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ABSTRACT

The world's first high throughput multi-beam mask writers (MBMW) have been realized by upgrading the existing MBMW Alpha and Beta tools with a 10x faster data path. In these tools a multi-beam column provides 262-thousand programmable beams of 20nm beam size. The current density is adjustable up to 1 A/cm^2, resulting in a total beam current of up to 1 µA. With the upgraded 120 Gbps data path full field 7nm node layouts can be printed in less than 10 hours. This upgrade completes IMS' first generation of multi-beam mask writers, which is called MBMW-101 and is meeting the requirements of the 7nm technology node.

Keywords: electron, multi-beam, mask writer, template writer, MBMW, OPC, ILT

1. INTRODUCTION

Very aggressive optical proximity effect correction (OPC) and curvilinear inverse lithography technology (ILT) layouts are mandatory to meet the demanding requirements of the sub-10nm technology nodes. To print these complex patterns with a conventional VSB (variable shaped beam) tool, very small shot sizes are needed, leading to an explosion of the total number of shots per mask. At the same time, resist sensitivity needs to be decreased significantly for each upcoming technology node in order to keep up with the stringent ITRS roadmap requirements regarding line width roughness (LWR) and resolution [1,2].

Linear mask write time improvements are not sufficient to compensate for the exponentially growing requirements of the upcoming 7nm and 5nm technology nodes. This can already be seen in today's mask write times for the most complex leading edge masks which have increased well beyond 30h for conventional VSB mask writers (cf. Ref. [3]). These extended write times of 30+ hours pose a severe problem since they are clearly failing to meet the industrial requirement of <24h write time for leading-edge masks.

Therefore, there is a strong industrial demand for a revolutionary improvement in mask writing technology for the 7nm technology node and beyond [4,5]. This demand is addressed by IMS' first commercially available high-throughput Multi-Beam Mask Writer MBMW-101 (cf. Figure 1).

MBMW-101 features 262-thousand 20nm-sized beams which are working in parallel. Due to the pixel-based exposure principle, throughput is completely independent of pattern complexity allowing any full field layout (100mm x 130mm) to be exposed in <10h. Furthermore, MBMW-101 is designed from scratch for resists requiring >100µC/cm² dose, making it perfectly suited for the 7nm technology node [6,7].

In this paper the performance of the first full blown MBMW-101 Alpha and Beta tools is discussed and their high-throughput capability is demonstrated.

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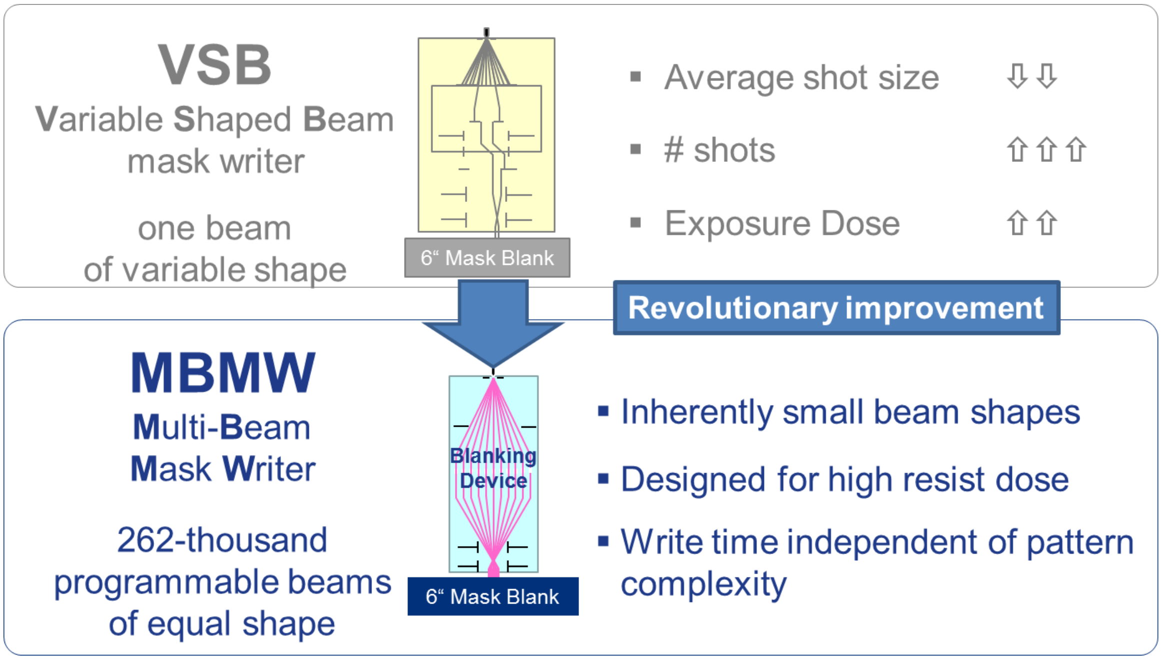

Figure 1: Revolutionary improvement in mask writing technology from standard 50keV electron VSB (variable shaped beam) to MB (multi-beam) mask writer tools required for the 7nm node and beyond in order to meet throughput, LWR, and resolution requirements for upcoming leading-edge masks

2. MBMW HISTORY

IMS' multi-beam technology behind MBMW-101 has been around for quite some time. Already in 2012, IMS realized the first MBMW proof-of-concept (POC) tool, which featured essentially the same electron optical column as the final HVM version (cf. Figure 2). With the POC tool it was already possible to demonstrate local litho-performance which met 7nm technology node requirements [1,6,7]. The main differences between POC and subsequent full field tools were the slow 4G datapath as well as the POC platform featuring a simple piezo driven test stage, which only allowed for local performance evaluations on 6" mask substrates. That is why no full mask exposures were possible on the MBMW POC tool.

The MBMW POC tool was followed by the MBMW Alpha tool in 2014. The Alpha tool was the very first multi-beam writer equipped with a production worthy platform, which was provided by JEOL. The highlight of this new platform was its novel air-bearing stage, which allowed for unprecedented precision and stability of the stage movement. Additionally, the datapath was upgraded from 4G to 12G, resulting in a 3x write time improvement. These improvements allowed the Alpha tool to expose full field masks with a main device of up to 100mm x 130mm in less than 15h.

In 2015 two MBMW Beta tools were installed and tested at two independent customer sites. These tools featured the same configuration as the Alpha tool and were used to optimize tool performance in a production environment. In this phase all tool corrections were thoroughly tested and proven to meet the targeted specifications. Furthermore, it was verified that no writer induced defects were generated on full field production layouts exposed by the MBMW Beta tools, verifying the robustness of the multi-beam datapath.

Finally in 2016, first high-throughput MBMW tools were realized by upgrading the Alpha and Beta tools with a novel 120G datapath (Figure 2). With this upgrade the final MBMW-101 configuration was completed, enabling <10h mask write times for any 100mm x 130mm layout at the final high performance write mode. An image of the upgraded MBMW-101 Alpha tool, which is located at the IMS production site, is shown in Figure 3.

MBMW-101	2012 POC	2014 ALPHA	2015 BETA	2016 HVM
Technology Node	Test 7nm	7nm	7nm	7nm
Beam Array Field	82µm x 82µm	82µm x 82µm	82µm x 82µm	82µm x 82µm
# programmable Beams	262,144 (512 x 512)	262,144 (512x512)	262,144 (512x512)	262,144 (512x512)
Datapath	4G	**12G**	12G	**120G**
6“ Mask Platform	IMS platform with Philips piezo test stage	**JEOL platform** with air-bearing vacuum stage	JEOL platform with air-bearing vacuum stage	JEOL platform with air-bearing vacuum stage
Mask Write Time (100mm x 130mm)	- (no full mask exposure possible)	**15h / mask**	15h / mask	**10h / mask**

Figure 2: History of MBMW-101

Figure 3: MBMW-101 ALPHA Tool

3. MBMW-101 PERFORMANCE VERIFICATION

First, in order to verify the performance of the novel 120G datapath of the MBMW-101 tools, extensive stand-alone studies were done wherein each subcomponent as well as the complete datapath was thoroughly tested against the targeted specifications. A summary of these test results is provided in Figure 4a, showing that data preparation, data rasterization, data buffering, data transmission and data processing were all successfully verified at data rates greater than 120 Gbps. Furthermore, end-to-end 120G datapath tests were performed in a dedicated test setup resulting in 0 datapath errors and simulated mask write times of less than 10 hours for a real 100mm x 130mm test layout.

In a second step, all relevant multi-beam corrections were successfully tested at full 120G data rate, verifying that there was no correction induced bottleneck for the throughput of MBMW-101 tools (cf. Figure 4b).

As a third verification step, first 120G test plates with all corrections enabled were printed on the MBMW-101 Alpha tool. Here, the 120G resolution capability was tested for any angle lines embedded in various background settings using a high-resolution pCAR resist. For these exposures the background pattern density was varied from 0% up to 75% demonstrating 30nm hp resolution capability at constant CD across the full range (see Figure 5).

(a)

MBMW-101		
Datapath	**Target**	**Status**
Dataprep	> 120 Gbps	✓
Rasterizer	> 120 Gbps	✓
Write Control Unit	> 120 Gbps	✓
APS	> 120 Gbps	✓
Datapath Errors	0 faulty bits	✓
Mask Write Time (100mm x 130mm)	< 10h	✓

(b)

	MBMW-101			
Standard e-beam Corr.	**PEC**	Proximity Effect Corrections	fully implemented	✓
	FEC	Fogging Effect Corrections	fully implemented	✓
	LEC	Loading Effect Corrections	fully implemented	✓
	GMC	Grid Matching Corrections	fully implemented	✓
	GCD	Global CD Corrections	fully implemented	✓
Special Corr.		Defective Beam Corrections	fully implemented	✓
		Stripe Butting Corrections	fully implemented	✓
		Drift Corrections (auto calibration)	fully implemented	✓

Figure 4: (a) 120G datapath performance tests successfully completed. (b) All multi-beam corrections are fully implemented and were tested at 120G data rate.

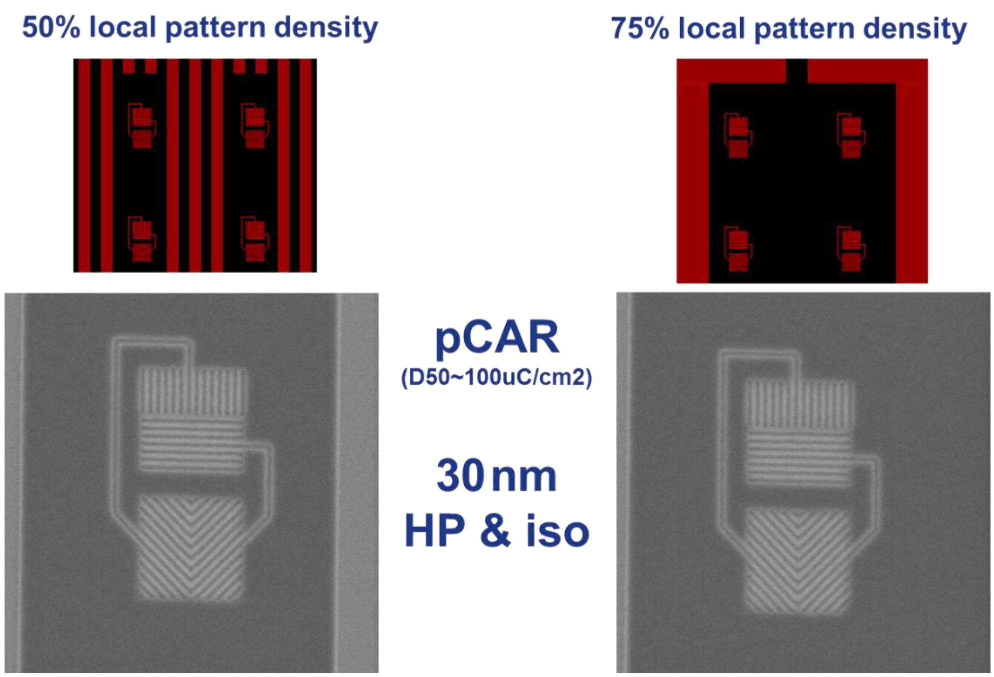

Figure 5: 30nm HP resolution for any angle lines was demonstrated with 120G datapath in pCAR. Resolution capability was verified for various background settings (left: 50% local pattern density; right: 75% local pattern density).

The MBMW-101 throughput capability was demonstrated with a dedicated 120G TPT Demonstration Plate (see Figure 6). The 100mm x 130mm test layout of this special demonstration plate was designed to include all kinds of challenging test cases and was successfully printed in less than 10 hours.

At the central top area of the layout, the IMS company logo and name were printed together with a description of the content of the plate ("120G Demonstration plate"). For this pattern the company logo was scanned and pixelated resulting in a true representation of the original design on the mask. This is highlighted in the optical microscope image on the right hand side of Figure 6 and serves as an additional demonstration that any arbitrary pattern can be printed by the MBMW-101 multi-beam mask writers.

At the top left and right corners of the layout curvilinear ILT test patterns were included to further verify the write performance for these complex structures at full speed. SEM images of some of these test structures can be seen in Figure 7a, showing good pattern fidelity and no resolution issues. As a matter of fact, using the MBMW-101 tool, even a full field ILT layout of 100mm x 130mm would have no impact on the exposure speed and could be printed within the same time (<10 h) as the 120G TPT Demonstration Plate discussed in this section. This is caused by the fact that MBMW-101 throughput is completely independent of pattern complexity.

At the bottom left and right corners of the 120G TPT Demonstration Plate three special "buckyball" any angle test patterns were printed. Here, one macroscopic buckyball spans across several millimeters in diameter and two smaller buckyballs are embedded in between the openings of the first (Figure 7b). The smallest printed buckyball is in the micrometer range demonstrating resolution capability for any angle assist features down to 20nm. These buckyball patterns are scanned representations of a conventional C60 molecule model further demonstrating the flexibility and resolution capability of the multi-beam architecture of MBMW-101.

The main device of the plate consists of aggressive vertical and horizontal OPC test structures (Figure 8). Here, the basic feature size of the horizontal and vertical lines is ~100nm, decorated with OPC structures down to 20nm. The vertical stripes seen in the optical microscope image on the left hand side of Figure 8 represent the different areas of horizontal and vertical OPC structures, which are repeated periodically across the plate. Sample SEM images of these OPC test structures were recorded at various plate locations showing stable performance during the complete plate exposure time of less than 10 hours.

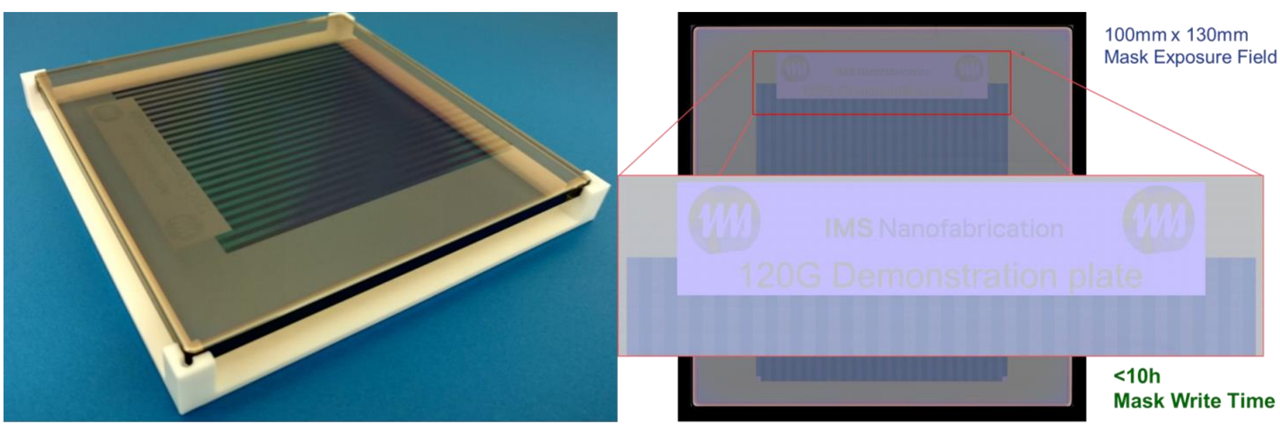

Figure 6: MBMW-101 throughput capability was demonstrated with a dedicated 120G TPT Demonstration Plate. 100mm x130mm test layout was printed in <10h using the standard high performance write mode with all corrections enabled.

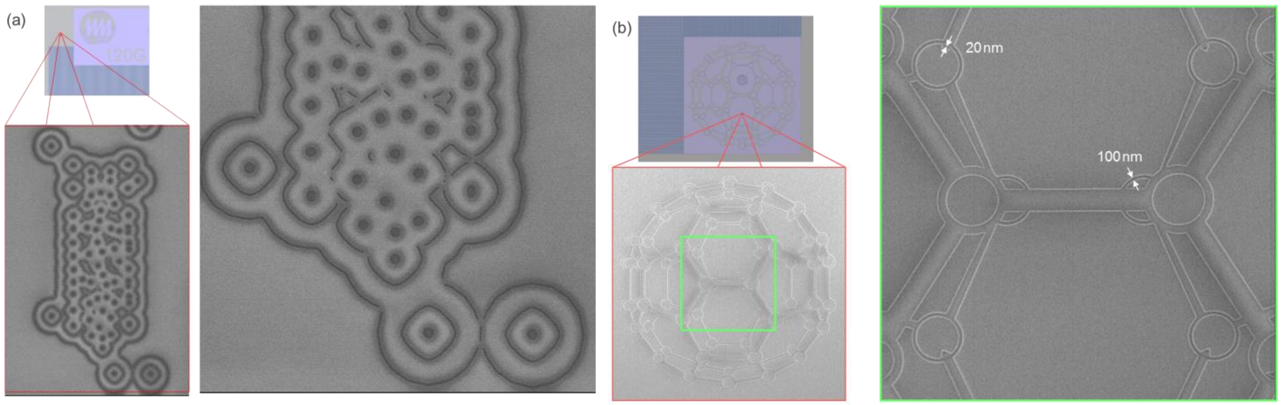

Figure 7: MBMW-101 throughput is independent of pattern complexity. (a) Curvilinear ILT test patterns were included in the top left and right layout of the 120G TPT Demonstration Plate. (b) “Buckyball” any angle test patterns were included in the bottom left and right demonstrating resolution capability down to 20nm.

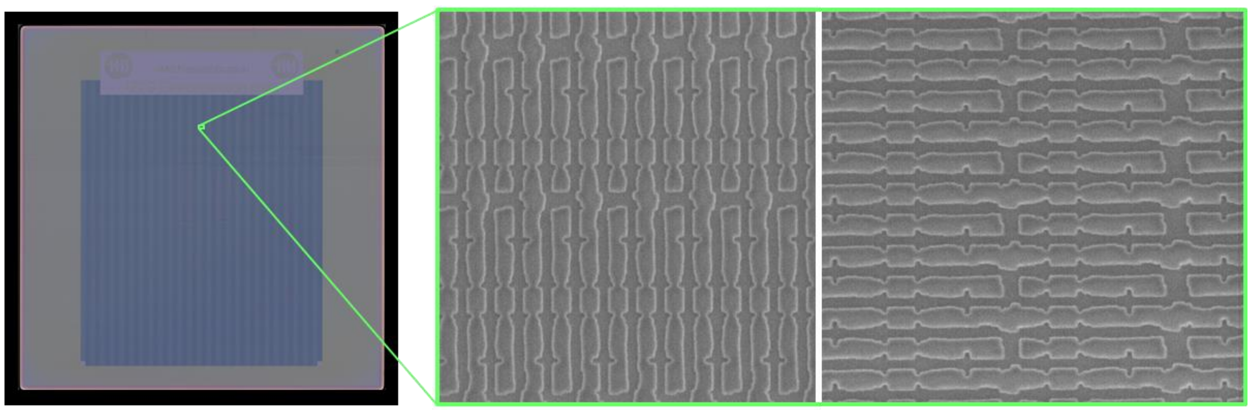

Figure 8: Main device of 120G TPT Demonstration Plate consists of aggressive vertical and horizontal OPC test structures with basic feature size of ~100nm decorated with OPC structures down to 20nm.

The litho-performance of the MBMW-101 tools was evaluated on full-field production plates at customer sites. A relative comparison of the performance before and after the 120G datapath upgrade is shown in Figure 9. Both, global CDU on product (Figure 9a) and global registration on product (Figure 9b) show an improved performance after the 120G upgrade and are meeting the 7nm technology node specifications. Overall, production plates printed with the upgraded MBMW-101 tools show better CDU, LER, registration and resolution capability compared to production plates printed before the upgrade.

Furthermore, no issues with data integrity were observed after the 120G datapath upgrade. Several full field production plates were inspected using standard inspection tools at two independent customer sites. None of the inspected production plates showed any writer induced defects.

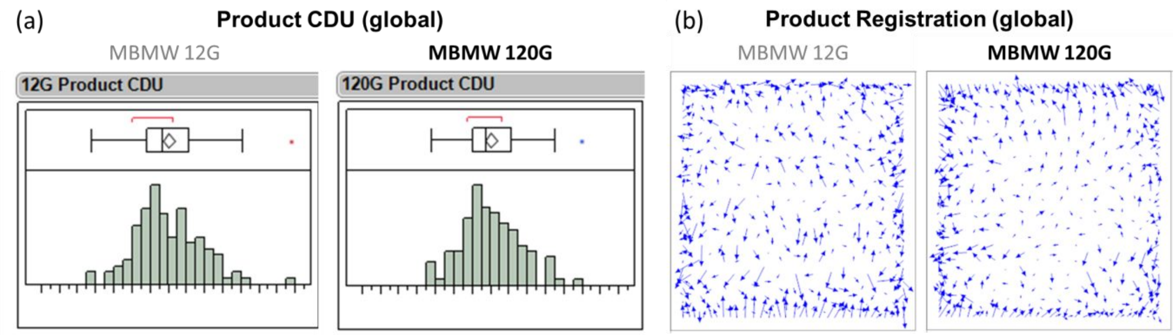

Figure 9: Comparison of litho-performance on full-field production plates before and after the 120G datapath upgrade (12G vs. 120G). (a) Global CDU on product is improved at 120G, meeting 7nm spec. (b) Global registration on product is improved at 120G, meeting 7nm spec.

4. SUMMARY

First high-throughput MBMW-101 multi-beam mask writers were realized by upgrading the existing Alpha Tool at IMS and two Beta Tools at two independent customer sites with a novel 120G datapath. With the upgraded MBMW-101 a total write time of less than 10 hours was demonstrated for a full 100mm x 130mm test layout, which included aggressive OPC, curvilinear ILT and any angle test patterns down to 20nm minimum features size.

MBMW-101 meets all requirements of the 7nm technology node while enabling the most complex patterns, smallest feature sizes and high dose at the same time and without any impact on throughput. This increases the flexibility of designs and facilitates the development of advanced products.

MBMW-101 is real and available as a commercial product. The new era of Multi-Beam Mask Writing has begun.

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