PHOTOMASK

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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.

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]

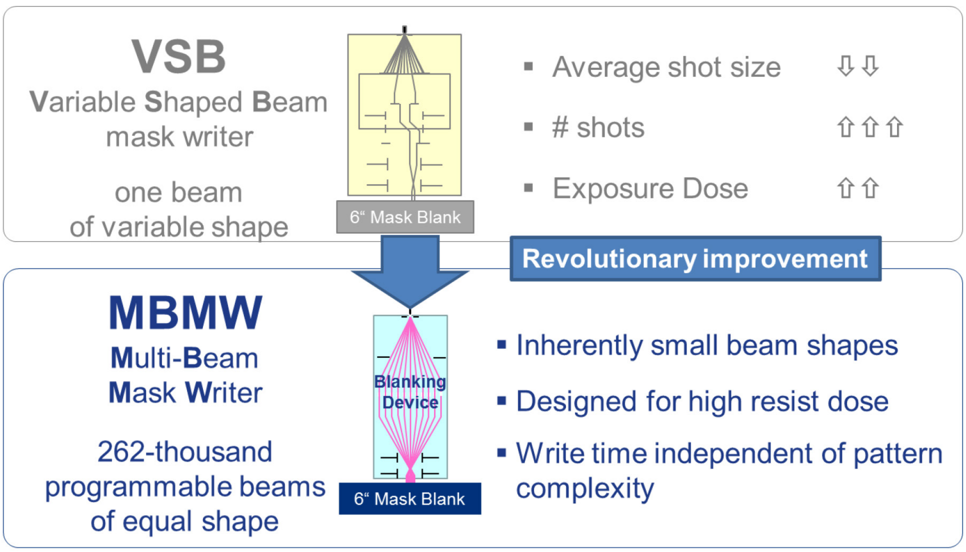

Figure 1. Revolutionary improvement in mask writing technology from standard 50keV electron VSB (variable shaped beam) to MB (multi-beam) mask writer tools required for the 7nm node and beyond in order to meet throughput, LWR, and resolution requirements for upcoming leading-edge masks.

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EDITORIAL

Easy to take for granted

Jim Wiley, BACUS President

Monitoring the development of mask making infrastructure for EUV lithography allows one to reflect on three critical DUV mask technologies that are easy to take for granted: defect-free blanks, pellicles and near-perfect defect detection. Although significant progress is underway, these three mask technologies remain challenging for EUV masks.

DUV mask blanks are so close to perfect that we take their defect-free status for granted. But it took DUV mask blank suppliers years of learning and technology development to reach this accomplishment. It also required the development of high sensitivity DUV blank inspection tools. EUV mask blanks defects are smaller (especially in height) and harder to detect. We are fortunate that both actinic and non-actinic tools that do an excellent job finding EUV mask blank defects have been developed. EUV mask blank defect reduction would be slow without these inspection tools. EUV mask blanks involve new materials and are more complex. EUV mask blank suppliers have worked very hard for the last few years and now can deliver low enough defect levels that the remaining defects can be mitigated by hiding under absorber or compensating repairs. But EUV mask blank defect mitigation adds additional steps and costs that would evaporate if EUV mask blanks could reach the same defect-free status we take for granted in DUV mask blanks. There is light at the end of this tunnel: last month, the first zero defect EUV mask blank was shown at the EUVL Symposium in Hiroshima. I look forward to the day that we can take defect-free EUV mask blanks for granted.

DUV mask pellicles that prevent repeating defects from fall-on particles are also easy to take for granted. Again, it took DUV mask pellicle suppliers years to achieve today's state-of the-art DUV pellicles that minimize impacts on the scanner lithography such registration errors. The challenge to prevent repeating defects with EUV pellicles appears larger. Fortunately, there are many EUV pellicle researchers and significant development efforts engaged around the world. Excellent EUV pellicle progress was reported at the EUVL Symposium last month. I look forward to the day that we can take EUV mask pellicles for granted.

Near-perfect DUV patterned mask defect detection is also easy to take for granted. Needless to say, DUV patterned mask defect inspection tool developers have employed multitudes of engineers to achieve this level of DUV mask defect detection perfection. For the next few years we will manufacture defect-free EUV patterned masks using the combination of actinic or non-actinic mask blank inspection, actinic mask defect review and defect detection with DUV and e-beam. I look forward to the day that we can take near-perfect EUV patterned mask defect detection for granted.

In September of 2017, the EUVL Symposium will join BACUS Photomask Technology in Monterey for a 4 day joint conference. I expect that we will see progress toward the goal of taking for granted defect-free EUV blanks, EUV pellicles and near-perfect EUV defect detection.

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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.

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

(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.

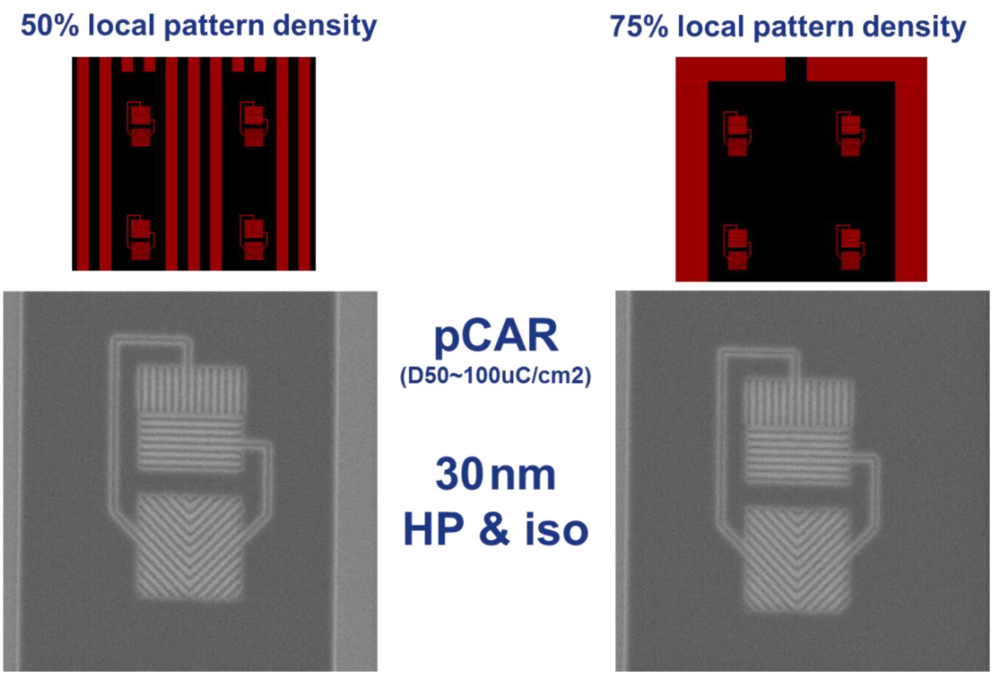

Figure 5. 30nm HP resolution for any angle lines was demonstrated with 120G datapath in pCAR. Resolution capability was verified for various background settings (left: 50% local pattern density; right: 75% local pattern density).

from scratch for resists requiring >100µC/cmÇ 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 highthroughput capability is demonstrated.

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

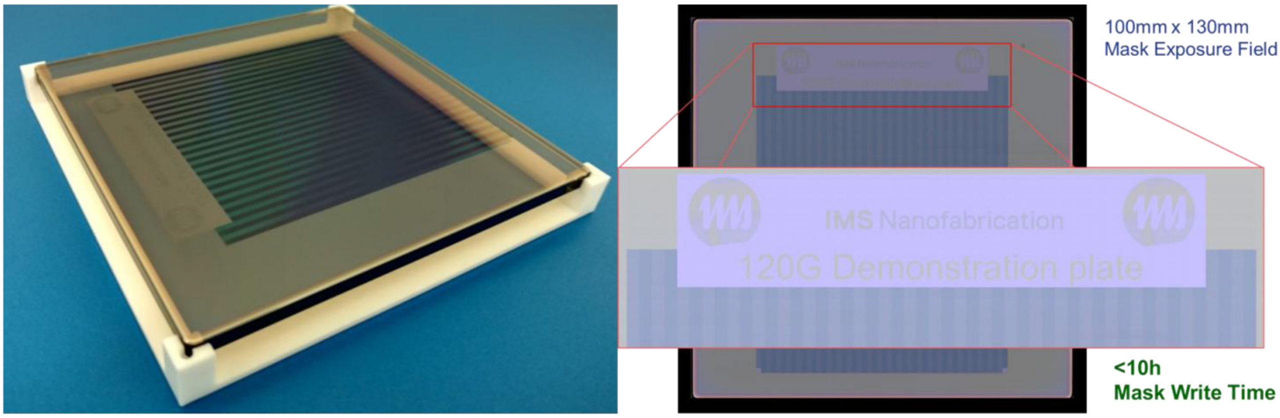

Figure 6. MBMW-101 throughput capability was demonstrated with a dedicated 120G TPT Demonstration Plate. 100mm x130mm test layout was printed in <10h using the standard high performance write mode with all corrections enabled.

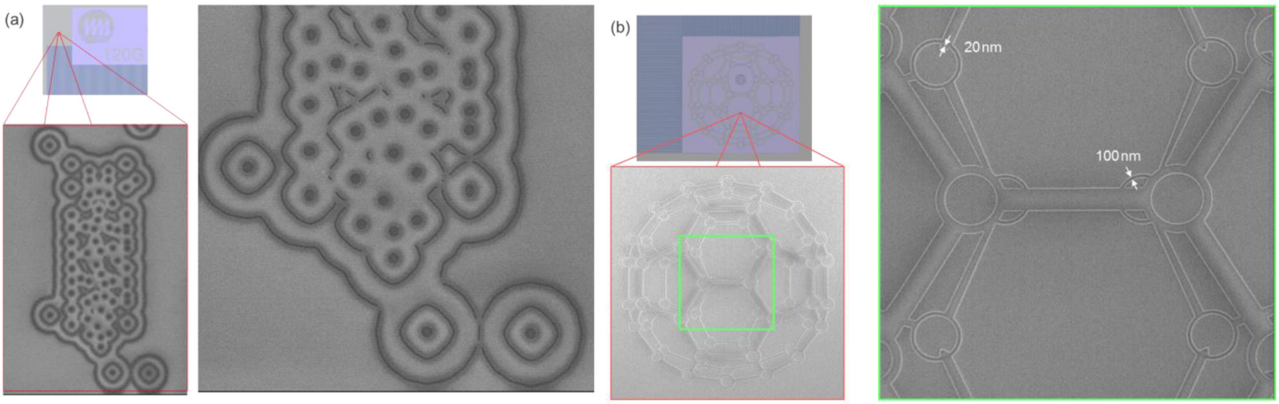

Figure 7. MBMW-101 throughput is independent of pattern complexity. (a) Curvilinear ILT test patterns were included in the top left and right layout of the 120G TPT Demonstration Plate. (b) "Buckyball" any angle test patterns were included in the bottom left and right demonstrating resolution capability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

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.

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-

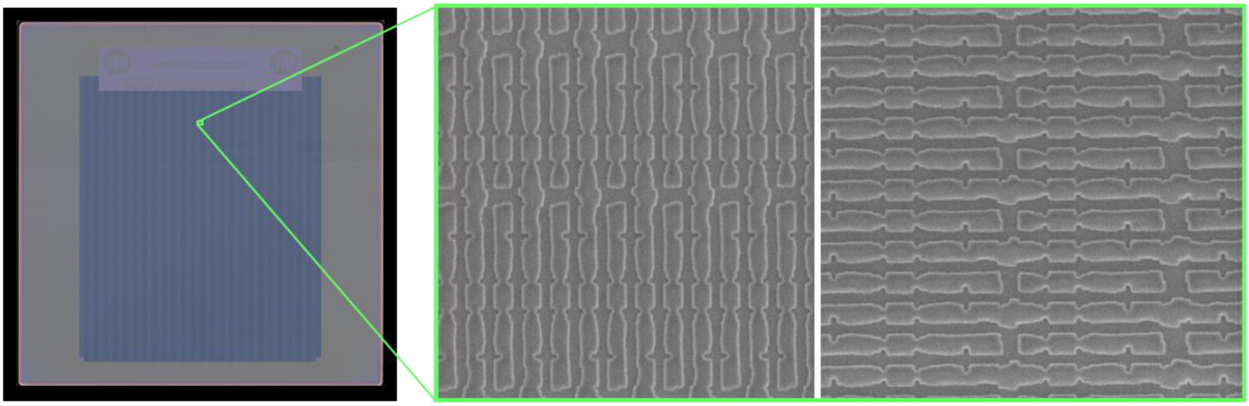

Figure 8. Main device of 120G TPT Demonstration Plate consists of aggressive vertical and horizontal OPC test structures with basic feature size of ~100nm decorated with OPC structures down to 20nm.

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).

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.

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.

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.

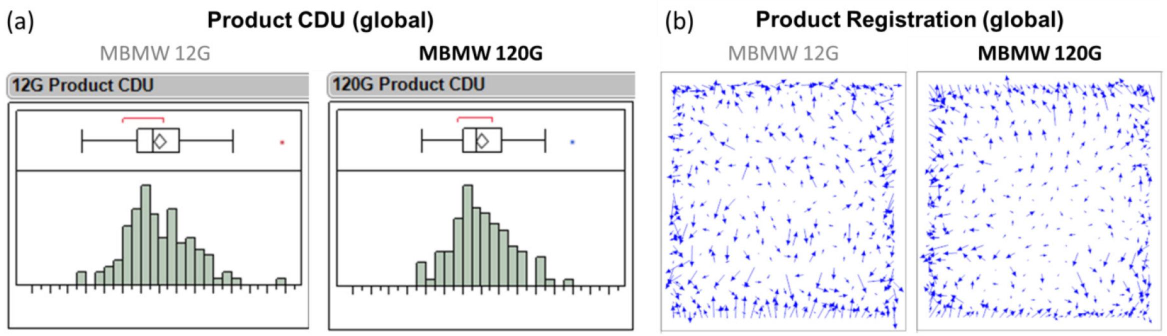

Figure 9. Comparison of litho-performance on full-field production plates before and after the 120G datapath upgrade (12G vs. 120G). (a) Global CDU on product is improved at 120G, meeting 7nm spec. (b) Global registration on product is improved at 120G, meeting 7nm spec.

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Industry Briefs

■ ASML Buys $1.1 Billion Stake in Zeiss Subsidiary

Business and Finance, *Optics.org*

Lithography company ASML is to invest $1.1 billion to buy a 25% stake in a subsidiary of Zeiss, in a bid to aid the development of high-numerical-aperture optics needed in future extreme ultraviolet (EUV) systems. The Carl Zeiss SMT (Semiconductor Manufacturing Technology) division is a key player in the lithography ecosystem, providing the high-performance optics used in ASML's scanner systems – and is described by ASML as its "most important strategic partner". This investment will support the anticipated $840 million spend on research and capital expenditure required over the next six years to bring the high-numerical-aperture (NA) optics to full commercialization.

ASML is already delivering EUV lithography equipment to some of the world's leading semiconductor manufacturers, with volume production of EUV-patterned chips slated to start in either 2018 or 2019. However, successful scaling of device features on the chips in the longer term will require optics with a higher numerical aperture than the current generation from Zeiss. "High-NA is the logical next step for EUV, as it circumvents complex and expensive 0.33 NA EUV multiple patterning," he said. "High-NA EUV is a robust way for chips to scale all the way down to the sub-3nm logic node in a single exposure with high productivity and reduced cost per feature."

In recent weeks ASML's key customers have said how they plan to introduce the technology, with Samsung expecting to adopt EUV for the 7nm node, and TSMC set to use it "extensively" in its 5nm logic device production. Intel has said that it could deploy EUV in its 7nm process flow, provided the uptime, availability, and throughput targets are met. Another chip maker, GlobalFoundries, is keeping its options open at 7nm.

http://optics.org/news/7/11/11

■ Siemens to Buy Mentor Graphics in $4.5B Deal

Junko Yoshida, *EE Times*

Siemens announced on November 14th, that it is buying Mentor Graphics in a $4.5 billion deal. Siemens is Europe's largest engineering conglomerate, best known for its power systems. But the German giant is keen on playing a big role in the so-called fourth industrial revolution — big data and IoT — thus adding its expertise in software-based design and automated manufacturing through acquisitions. Mentor acquisition is Siemens's biggest deal in the industrial software sector since it bought UGS, a U.S.-based industrial design software group, for $3.5 billion in 2007.

In the press announcement, Siemens stressed that the company is becoming "unique digital industrial player to offer mechanical, thermal, electrical, electronic and embedded software design capabilities on a single integrated platform." The German industrial conglomerate hopes to own a full suite of products to design solutions for everything from planes, trains and automobiles to wearable devices. Siemens also hopes Mentor can foster the German company's holistic strategy for "mechatronics" — technology that combines mechanical engineering with electronics.

Klaus Helmrich, member of the Managing Board of Siemens, said in a statement, "With Mentor, we're acquiring an established technology leader with a talented employee base that will allow us to supplement our world-class industrial software portfolio. It will complement our strong offering in mechanics and software with design, test and simulation of electrical and electronic systems." Wally Rhines, chairman and CEO of Mentor, said in a statement: "Siemens is an ideal partner with financial depth and stability, and their resources and additional investment will allow us to innovate even faster and accelerate our vision of creating top-to-bottom automated design solutions for electronic systems."

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Calendar

2017

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SPIE Photomask Technology and SPIE International Conference on Extreme Ultraviolet Lithography 2017
11-14 September 2017
Monterey, California, USA

The 24th Symposium on Photomask and NGL Mask Technology
5-7 April 2017
Pacifico Yokohama
Yokohama, Japan

The 33rd European Mask and Lithography Conference EMLC 2017
27-29 June 2017
Hilton Hotel
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