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Performance of the Proof-of-Concept Multi-Beam Mask Writer (MBMW POC)

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ABSTRACT

Two proof-of-concept electron multi-beam mask writer tools (MBMW POC) have been realized, which are utilizing 262,144 programmable beams of 20nm beam size and 50keV beam energy to pattern 6” mask blanks. Tool characterization details and test results are outlined. Especially, LMS IPRO4 measurements (after development inspection) of short term and long term stability of the 82µm x 82µm beam array field are discussed. Scale stability of the beam array field of 0.1nm per day is demonstrated.

1. Introduction

Pattern complexity is rising dramatically due to the fact that 193nm water immersion lithography is extended to the sub-20nm technology nodes. In order to make this extension work, leading edge masks require very aggressive optical proximity effect correction (OPC) and complex inverse lithography technology (ILT) patterns. To print these kinds of patterns properly with a state-of-the-art VSB (variable shaped beam) tool, however, very small shot sizes are needed, leading to an explosion of the total number of shots per mask. For the 18nm node, complex masks are already well beyond 1x10E12 shots per mask; i.e. ~4 T-shots for single patterning and ~1.5 T-shots for double patterning [1]. Such a 4 T-shot mask is predicted to translate to ~30h of write time using a VSB mask writer operating at 800 A/cm^2 [1]. Since the current trend shows an exponential increase in pattern complexity, linear improvements in mask writer performance will not be able to keep mask write times

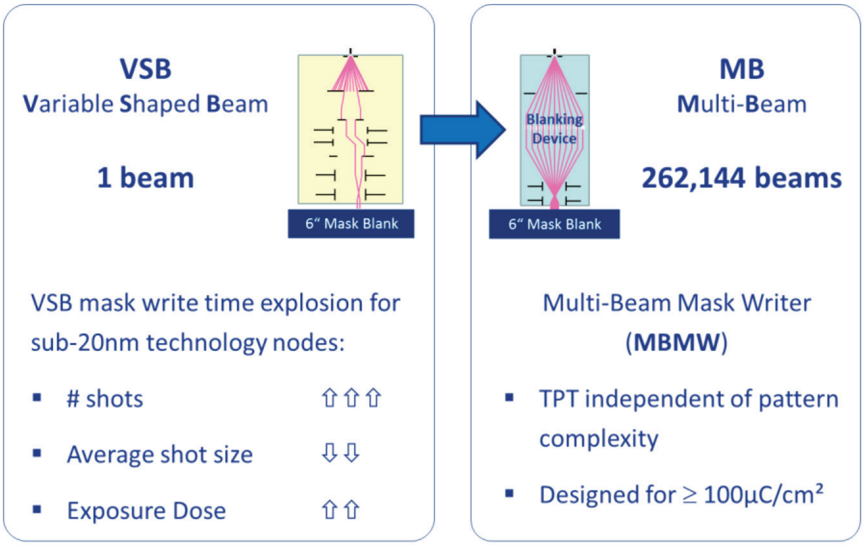

Figure 1. Change from 50keV electron VSB (variable shaped beam) to MB (multi-beam) mask writer tools.

TAKE A LOOK INSIDE:

INDUSTRY BRIEFS
—see page 7

CALENDAR
For a list of meetings
—see page 8

8880-50

EDITORIAL

2013 ends as it began - it is cold here in New York.

Paul W. Ackmann, *GLOBALFOUNDRIES Inc.*

We had a very good conference at BACUS this year. We continued the single track approach with a good number of papers. This will be the same approach in 2014. We have almost all members returning for the 2014 conference committee, and I look forward to working them as session chairs and co-chairs. I am truly grateful for the great support we get from the BACUS membership. I look forward to working with all as the Chairman this year, along with my co-chair Hayashi-san.

The year started with thoughts of consolidation among the mask conferences. We have very close linkage and it continues to improve with the goal of increased synergy ongoing. The three good conferences cover the calendar in Japan (PMJ-April), Germany (EMLC – June), and United States (BACUS – Sept). The industry continues to progress toward a new lithography introduction. We have made many PowerPoint presentations of where we are going and when we will get there. We are not there yet, but we can get closer by adding more results to presentations at our mask conferences in 2014.

So, 2014 is a year nearer for EUV to go into manufacturing. There are many new challenges but the direction is clear. Pellicles are needed for optical masks, and now EUV sees the need for these. The next generation of EUV tools is being delivered to increase the penetration of EUV technology and continues the need for better masks. Defectivity, parametric control, and ultimately lifetime will be driven by the EUV Lithography teams. We can hope that the mask part will be ready for prime time when EUV ramps into HVM.

With EUV making inroads one could say that optical will need less work. This could be no further from the truth. For now, all nodes to 10 nm (sub 20 nm 1/2 pitch) will be optical. If anyone thinks EUV is a challenge then they have not spent too much time dealing with double or triple patterning. The use of multiple optical extensions and patterning solutions for flash, DRAM and even logic are well known. Regardless the mask process is a challenge.

The requirements for double patterning have been known for a long time. Triple (or more) patterning for the tight pitches of sub-20 nm 1/2-pitch will challenge the reticle process and tool matching. The good news is that the pattern file size has not grown as fast as we thought. The bad news is that it takes three or more masks to pattern a single wafer masking level. I still think 28 nm node Metal 1 leads the file size competition until single patterning EUV becomes the mainstay of the industry. E-beam requirements continue to become more complex. The challenges are being met with next generation tools, including good results for the IMS multi-beam system. I expect even more results for the extension of optical and other technologies in 2014.

The larger reticle format was discussed in a couple of forums this year. I was reminded by many that this was the third look at a larger format for high end reticles. The SEMATECH survey for larger glass identified a couple of opportunities for field usage and magnifications for High NA EUV scanners. Larger glass came up and was supported by the scanner users, while most of the commercial mask makes preferred to stay with the standard glass. After the panel and with more reflection it is clear to me that the need for bigger glass may occur, but it will not drive a decision and would only happen as the next step in productivity improvements. I think the BACUS Panel discussion really drove home the Return on Investment requirement for any glass size change optical or EUV. I would say the third time was the charm, perhaps not for implementation but to define the path forward if it were to happen.

The discussions about the industry consolidation will continue. The higher percentage of high end captive control continues to drive changes in the industry as tools and process tend to follow the capital. We will watch the trends that are in progress for EUV, new tools, and processes should show us good results at BACUS 2014. I look forward to the challenges as we move 2014. I enter this year with renewed vigor and optimism regarding the mask business and our challenges to meet the lithography needs of our customers.

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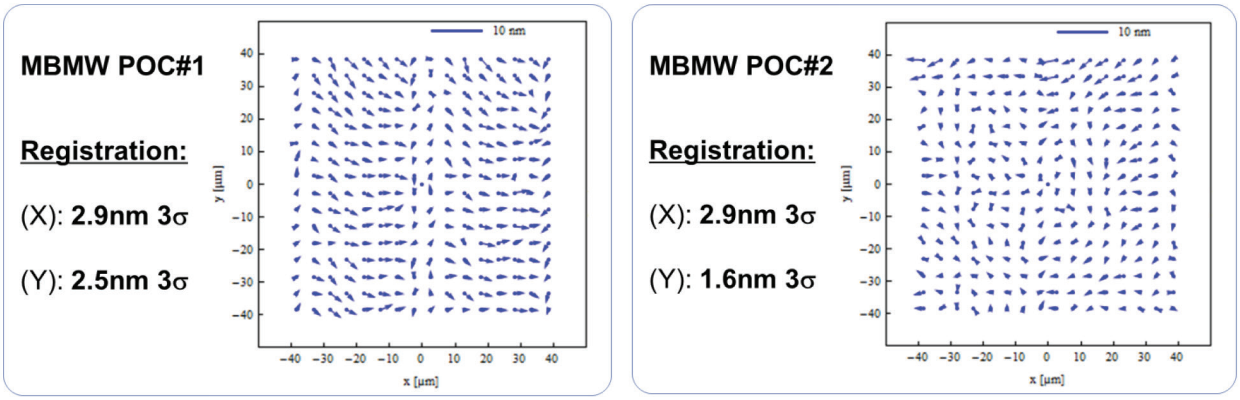
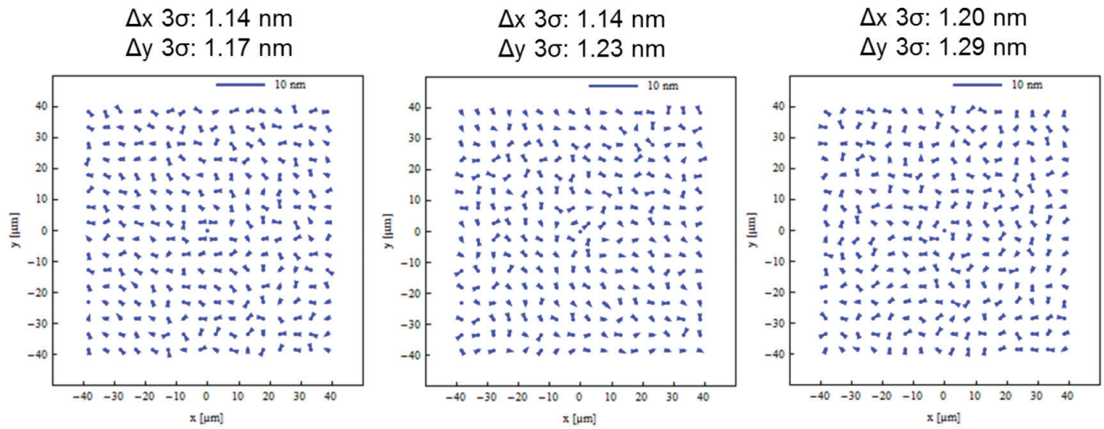


Figure 2. Registration within 82μm x 82μm beam array field: LMS IPRO4 measurements for POC#1 (left) and POC#2 (right). (The 1.3nm 3sigma LMS IPRO4 short term repeatability error [3] was taken out.)


Δx 3σ: 1.14 nm
Δy 3σ: 1.17 nm

Δx 3σ: 1.14 nm
Δy 3σ: 1.23 nm

Δx 3σ: 1.20 nm
Δy 3σ: 1.29 nm

Figure 3. Short term Registration stability; LMS IPRO4 difference values of exposures within 15min time interval as obtained with the MBMW POC#2 tool.

within acceptable limits. Furthermore, the mask exposure dose needs to be constantly increased – i.e. resist sensitivity needs to be decreased – in order to keep up with the stringent ITRS roadmap requirements regarding line width roughness (LWR) [2]. For example, for the 11nm HP mask technology node the exposure dose will need to be increased to ~50μC/cm^2 and for the 6nm HP mask technology node to ~100μC/cm^2 (see Figure 6).

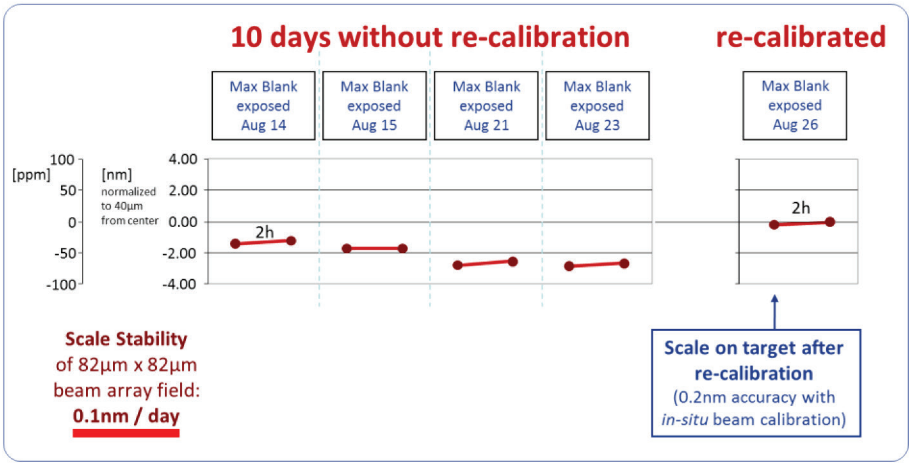
Consequently, mask write times are bound to explode for conventional VSB mask writers for sub-20nm technology nodes due to the fact that the number of shots is increasing exponentially while the exposure dose needs to be increased at the same time. Linear performance improvements will to a large extend already be eaten up by the projected dose increase for future sub-20nm nodes. Therefore, there is a strong industrial need for a revolutionary improvement in mask writing technology, which is going to be provided by Multi-Beam Mask Writers (Figure 1) [3].

The IMS Multi-Beam Mask Writers (MBMW) provide currently 262,144 20nm-sized beams which are working in parallel. Due to the pixel-based exposure principle, throughput is completely independent of pattern complexity. Furthermore, the IMS MBMWs are designed from scratch for resist requiring >100μC/cm^2 dose, making them very well suited for the 11nm HP technology node and beyond [4,5].

The principles of the IMS proof-of-concept multi-beam mask writer (MBMW POC) and exposure results demonstrating multi-beam writing with 0.1nm address grid were published recently [5]. In 2013 IMS Nanofabrication successfully realized a second MBMW POC tool. This paper focuses on registration and stability results obtained with the 2 MBMW POC tools.

2. MBMW POC Registration

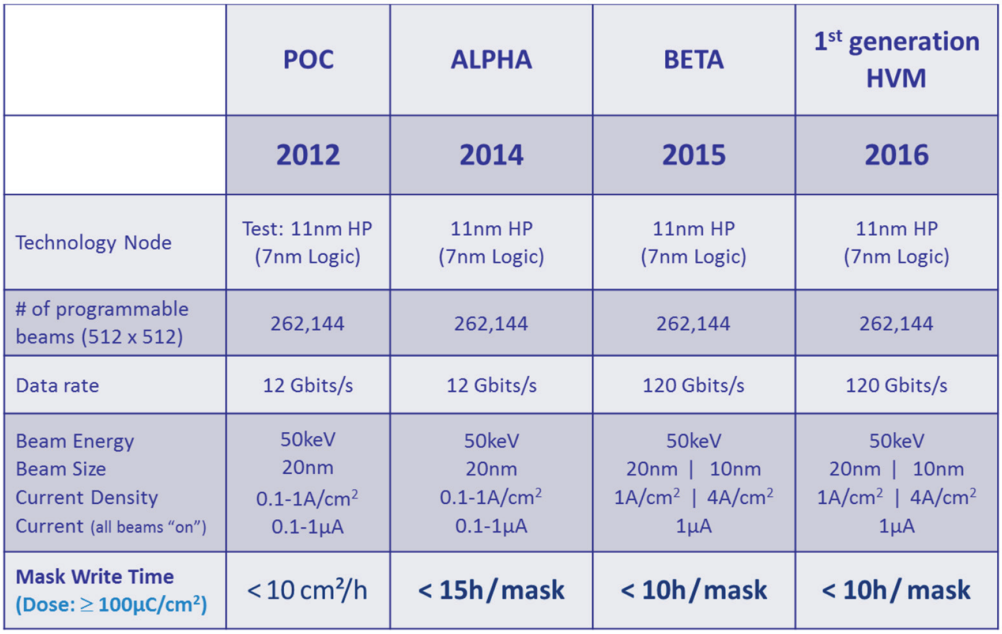
The MBMW POC beam array field consists of a 512 x 512 matrix of 262,144 programmable beams of 20nm beam size. The pitch between the beams is 160nm in X as well as in Y direction. Thus, the beam array field covers an area of 81.92μm x 81.92μm. With respect to "Registration" (placement accuracy relative to design), the MBMW POC specification target is to



Scale Stability of 82µm x 82µm beam array field: **0.1nm / day**

Scale on target after re-calibration (0.2nm accuracy with *in-situ* beam calibration)

Figure 4. Long term stability of MBMW POC#1 tool and effectivity of in-situ scale calibration.



	POC	ALPHA	BETA	1st generation HVM
	2012	**2014**	**2015**	**2016**
Technology Node	Test: 11nm HP (7nm Logic)	11nm HP (7nm Logic)	11nm HP (7nm Logic)	11nm HP (7nm Logic)
# of programmable beams (512 x 512)	262,144	262,144	262,144	262,144
Data rate	12 Gbits/s	12 Gbits/s	120 Gbits/s	120 Gbits/s
Beam Energy Beam Size Current Density Current (all beams "on")	50keV 20nm 0.1-1A/cm^2 0.1-1µA	50keV 20nm 0.1-1A/cm^2 0.1-1µA	50keV 20nm | 10nm 1A/cm^2 | 4A/cm^2 1µA	50keV 20nm | 10nm 1A/cm^2 | 4A/cm^2 1µA
Mask Write Time **(Dose: ≥ 100µC/cm^2)**	< 10 cm^2/h	**< 15h / mask**	**< 10h / mask**	**< 10h / mask**

Figure 5. MBMW roadmap.

achieve 3.0nm 3sigma. This target was met for both MBMW POC tools as shown in Figure 2. Here, the locations of 16 x 16 crosses, which are evenly distributed across the whole 81.92µm x 81.92µm image field, were measured using an LMS IPRO4 metrology tool [6].

Recently, *in-situ* calibration capability and an antifogging plate were added to the MBMW POC tool columns. These improvements are required to improve Registration further down to the 2.0nm 3sigma target of the first HVM tool.

3. Short Term Stability of the MBMW POC Tool

Figure 3 shows LMS IPRO4 measurement results of short term Registration stability (15min between exposures). The results are within the 1.3nm 3sigma short term repeatability error of the LMS IPRO4 metrology tool. Here, a reference grid is generated by averaging the 3 Registration stability measurement results and the deviations of the individual exposures from the reference grid are plotted in Figure 3.

4. Long Term Stability of the MBMW POC Tool and In-situ Adjustment

A long term stability test of the MBMW POC#1 tool was performed: The system was kept in operation for 10 days without any re-calibrations, exposing mask blanks on the days indicated in Figure 4.

The LMS IPRO4 measurements show that the scale of the 82µm x 82µm beam array was stable within 0.1nm per day.

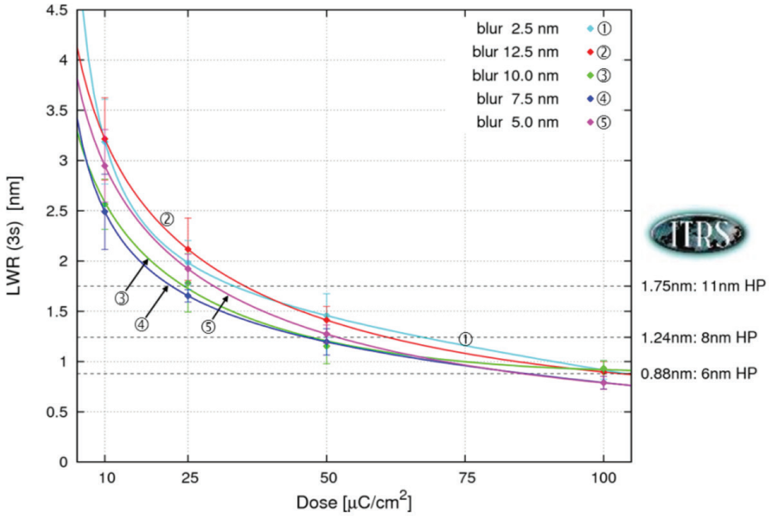


Figure 6. Monte Carlo simulation of the 3sigma line width roughness (LWR) for 30nm line width vs. exposure dose. Parameter is the combined tool and resist 1sigma blur. The optimum total 1sigma blur is between 5nm and 7.5nm, meeting the requirements for the 6nm HP mask technology node when using a resist exposure dose of 100µC/cm^2.

Using *in-situ* beam calibration (which has an accuracy of 0.2nm), the scale was re-calibrated and a new mask blank was exposed. Subsequent LMS IPRO4 measurements demonstrated the success of in-situ scale re-calibration (Figure 4, right).

5. MBMW Roadmap

The IMS MBMW roadmap is shown in Figure 5. The present focus is the MBMW Alpha tool, which combines one of the existing electron optical columns with a novel platform, featuring a laser interferometer controlled air-bearing vacuum stage.

In parallel, two MBMW Beta tools are being realized where the column can provide 262,144 programmable beams of 20nm or 10nm beam size (with *in-situ* means for changing the beam size [7, Figure 2]). In order to maintain productivity, the current density is enhanced to 4A/cm^2 when operating the column with 10nm beams, thus obtaining 1µA current (with all beams "on"). Concurrently, the data path speed is enhanced from presently 12Gbits/s to 120Gbits/s. The first generation HVM (high volume manufacturing) MBMW tools are planned to be delivered in 2016.

Throughput of the MBMW tools is independent of pattern data complexity. Furthermore, the MBMW Beta and HVM tools are designed from scratch to achieve <10h mask write times using 100µC/cm^2 resists.

6. MBMW Extendibility to Sub-10NM Halt-Pitch Technology Nodes

There is the need to enhance the resist exposure dose in order to meet the ITRS requirements on low line edge and line width roughness (LER/LWR), as shown in Figure 6. At the same time, there is the need to provide a low column as well as low resist blur so that the total 1sigma blur is < 10nm (see Figure 6).

The realized MBMW column has a 1sigma blur of 5nm, which was also verified experimentally [7, Figure 4]. Figure 7 shows the different column blur contributions as well as the total column blur, which is virtually current-independent. Thus, in combination with a suitable resist material, the realized column is suitable for the 8nm HP and 6nm HP mask technology nodes.

In order to meet the same throughput targets for the sub-10nm nodes using smaller beam sizes, there is the potential to increase the number of programmable beams to ca. 0.5Mio beams for the 8nm HP mask technology node and to ca. 1Mio beams for the 6nm HP mask technology node.

Therefore, from a throughput as well as a blur perspective, the IMS MBMW technology is well suited to meet the sub-10 nm HP technology node requirements.

7. Summary

Two MBMW POC systems were realized and used to confirm multi-beam writing principles and to demonstrate lithographic performance. The key results are listed below:

- Registration is within 3nm 3sigma POC target specifications, optimization to 2nm 3sigma in progress
- Short term (15min) stability of the POC column distortion fingerprint is within the measurement accuracy of the metrology tool (LMS IPRO4).
- Scale stability of the POC column was found to be < 0.1nm per day. *In-situ* recalibration works within the specified accuracy of 0.2nm.
- 5nm 1sigma column blur was achieved across 82µm x 82µm beam array field with 262,144 programmable beams of 20nm size and 50keV energy allowing to meet the stringent ITRS requirements for LWR for the sub-10nm mask technology nodes.
- For IMS MBMW tools, throughput is independent of pattern complexity.
- Multi-beam writing with 0.1nm address grid was demonstrated in pCAR as well as HSQ.

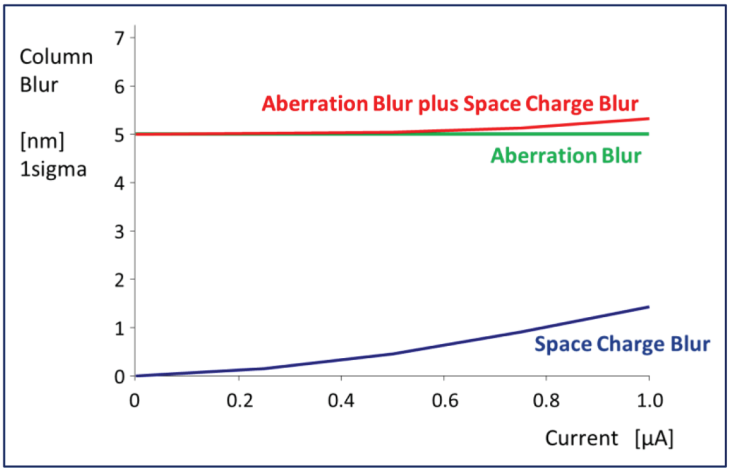


Figure 7. Contributions to the 1sigma blur of the realized multi-beam column.

The program is on track for the MBMW Alpha tool in 2014, for Beta in 2015 and 1st generation HVM tools in 2016.

There is MBMW extendibility to sub-10nm mask technology nodes:

- Resolution and blur of the realized electron optical column are well suited for the 8nm HP and 6nm HP technology nodes
- A novel platform with air-bearing vacuum stage is used which meets the sub-10nm HP requirements
- The number of programmable beams can be increased to ca. 0.5Mio for the 8nm HP mask technology node, and to ca. 1Mio for the 6nm HP technology node

⇨IMS MBMW tools will be able to achieve < 10h mask write times for sub-10nm mask technology nodes.

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Industry Briefs

Intel Expects Pellicle is Needed for EUV Masks

By **Vivek Bakhsh,** Solid State Technology

Mark Phillips of Intel in his keynote talk in 2013 Source Workshop (Nov 3-7, 2013, Dublin, Ireland) said that 40-80 W of stable sources with master oscillator power amplifier (MOPA) technology and prepulse, linked to production level EUVL scanners (NXE 3300B), are needed to reestablish confidence in EUVL and process development. He expects these power levels to be available in the first half of next year, in keeping with the timeline of HVM insertion in 2017 by his company. As Intel now expects that a pellicle will be needed for EUVL scanners, this position will help resolve the issue of choosing of actinic vs. e-beam technology for mask defect inspection, as only photon-based inspections can be used with a pellicle. This will hopefully result in an increased engagement between metrology source suppliers and mask defect inspection tool makers.

Photronics Announces Joint Venture in Taiwan with Dai Nippon Printing

Dow Jones Institutional News

Photronics, Inc., today announced an agreement with DNP to merge Photronics Semiconductor Mask Corporation (PSMC), a majority owned subsidiary of Photronics, with DNP Photomask Technology Taiwan Co., Ltd. (DPTT), a wholly owned subsidiary of DNP, to form a joint venture focused on serving semiconductor manufacturers in Taiwan. Photronics and DNP will own 50.01% and 49.99% of the joint venture, respectively, and its financial statements will be included in the consolidated financial statements of Photronics, Inc.

The joint venture will leverage DNP's leading technology processes in logic photomasks and PSMC's advanced technology processes in memory photomask manufacturing and operating scale. It will operate under the name Photronics DNP Mask Corporation (PDMC) and current PSMC President, Dr. Frank Lee, is expected to be named General Manager of the joint venture.

SEMATECH Partners with SUSS MicroTec to Speed Commercialization of Mask Lithography for Semiconductor Manufacturing

Journal of Engineering

SUSS MicroTec, a leading supplier of equipment and process solutions for the semiconductor and related markets, and SEMATECH, a global consortium of semiconductor manufacturers, announced that SUSS MicroTec's photomask equipment division has partnered with SEMATECH to investigate and develop extreme ultraviolet lithography (EUVL) substrate and blank cleaning technologies that will accelerate process availability for extreme ultraviolet pilot line manufacturing. As a SEMATECH member, SUSS MicroTec's photomask equipment division will collaborate with the consortium's EUV mask experts to focus on improving the cleaning yield on EUVL mask blanks, patterned masks and non-patterned EUVL substrates. The long-term goal of this collaboration is to increase the manufacturing yield for substrates and mask blanks with the lowest defect counts at nonprintable defect sizes.

Photronics Reports Fourth Quarter and Fiscal 2013 Results

Business Wire

Constantine ("Deno") Macricostas, Photronics' chairman and chief executive officer, commented: "Photronics' fourth-quarter revenues reflect reduced high-end IC photomask sales, which were affected by decreased demand in memory photomasks due to customer delays in transitioning to new nodes and a delay in fully completing the qualification process with a key Asian foundry customer".

Sales for the fourth quarter of fiscal 2013 were $106 million, compared with $104.2 million for the fourth quarter of fiscal year 2012. Sales of semiconductor photomasks were $79.8 million, or 75% of revenues, during the fourth quarter of fiscal 2013, and sales of flat panel display (FPD) photomasks were $26.2 million, or 25% of revenues. Sales for the 2013 fiscal year were $422.2 million, compared with $450.4 million for the 2012 fiscal year. For the 2013 fiscal year, sales of semiconductor photomasks were $320.6 million, or 76% of revenues, and sales of FPD photomasks were $101.6 million, or 24% of revenues. Analysts on average were expecting earnings of 12 cents on revenue of $112.6 million in the quarter ended November 3, however, Photronics's earnings were 6 cents to 7 cents per share, on revenue of about $105-$106 million.

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About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

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2014

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San Jose Convention Center
and San Jose Marriott
San Jose, California, USA

Late Submissions may be considered by the conference chairs. Please send all late submissions to Pat Wight at patw@spie.org

SPIE Photomask Technology

16-18 September 2014
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