PHOTOMASK

BACUS—The international technical group of SPIE dedicated to the advancement of photomask technology.

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2nd Place Best Poster - PM14

Study of high sensitivity DUV inspection for sub-20nm devices with complex OPCs

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ABSTRACT

EUV lithography has been delayed due to well-known issues such as source power, debris, pellicle, etc. for high volume manufacturing. For this reason, conventional optical lithography has been developed to cover more generations with various kinds of Resolution Enhancement Techniques (RETs) and new process technology like Multiple Patterning Technology (MPT). Presently, industry lithographers have been adopting two similar techniques of the computational OPC scheme such as Inverse Lithography Technology (ILT) and Source Mask Optimization (SMO).[1] Sub-20 nm node masks including these technologies are very difficult to fabricate due to many small features which are near the limits of mask patterning process. Therefore, these masks require the unseen level of difficulty for inspection. In other words, from the viewpoint of mask inspection, it is very challenging to maintain maximum sensitivities on main features and minimum detection rates on the Sub-Resolution Assist Features (SRAFs). This paper describes the proper technique as the alternative solution to overcome these critical issues with Aerial Imaging (AI) inspection and High Resolution (HR) imaging inspection.

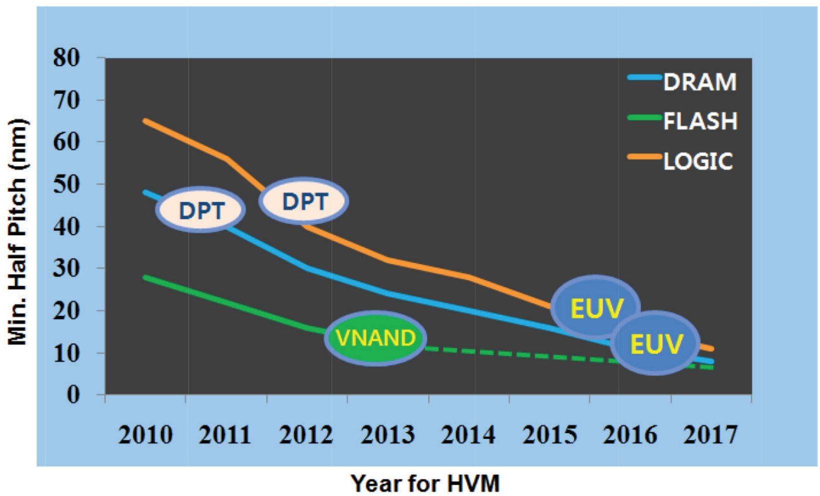

Figure 1. Lithography and minimum half pitch as years of HVM.

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SPIE.

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EDITORIAL

2014 in Retrospective

Paul Ackmann, GlobalFoundries Inc.

In retrospect, 2014 was a busy and fruitful year. This was the first year I was able to attend all of the photomask conferences and one other.

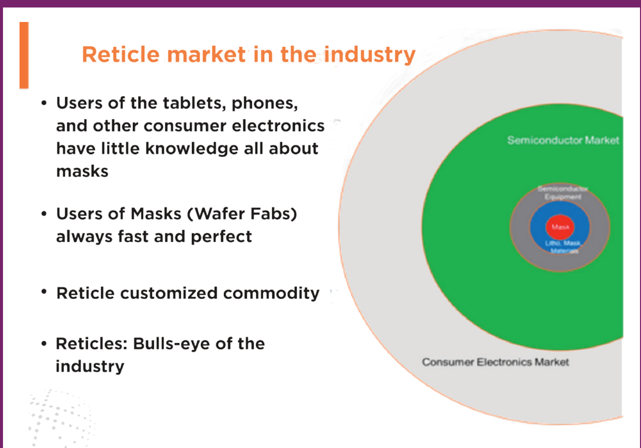
Attending CSTIC was my first trip to Shanghai and China. The CSTIC conference was held with a mix of English and Chinese presentations and provided the opportunity to meet many new people. The mix of technology sessions with language differences made the sessions quite a challenge. The native Chinese speakers' presentations were well done and I could often follow the key details more easy then the English versions. The immensity of Shanghai cannot be understated and must be seen to be appreciated.

PMJ session in Japan is a perennial trip and, as always, the meeting and conference was very informative. Side meetings were held during PMJ to discuss the decline in papers and attendance. There were several potential actions discussed but the final conclusion was to maintain the status quo. The highlight of PMJ, after the technical papers, was the dinner, entertainment, and Videos from Hayashi-san (DNP) and Morimoto-san (Toppan). Both videos, as always, were very special and creative. Hayashi-san expanded his directorial and cinematographic capabilities by employing a drone to capture a flight through, and above, a grove of Japanese Cherry Blossom trees. The conference and proceeding were well received.

In June, continuing the new warm-weather time slot, the EMLC conference was held in Dresden. EMLC was run by Uwe (as it has been for 28 years) and held in the Hilton Hotel. Unlike the prior year, it did not flood this time. Since I spent four years in Dresden, I could say much about the city that I dearly love. The people, the views, the history, and the beer always bring back fond memories. The conference was well attended with 160 attendees. Next year EMLC will move to Eindhoven and be co-sponsored by ASML.

The last conference of the year was Bacus, which I had the honor of coordinating as conference chair. Thankfully, cancelations were few, attendance was high, and Michael Postek was there to help. The conference drew 440 participants which maintained the attendance levels of recent years.

The SPIE Bacus Conference, viewed from the perspective of Chairman, was a great conference. It was the culmination of a very good year and I enjoyed working with a great group of people. The joint conference with the Scanning Microscopies Conference, run by Dr. Michael Postek, was a good addition and the hard work by Michael and the SPIE team to seamlessly integrate these conferences was appreciated. The 2015 conference will follow this same format and I hope this is the beginning of long-term joint conference event. At the end of the year, the BACUS Steering Committee elected me to succeed Frank Abboud as President.



Bulls-eye depiction of Industry revenue scaled by area. P. Ackmann, CSTIC 2014.

My current deep involvement with BACUS is the direct result of the help of Frank Abboud. Frank started with Tom Faure in the BACUS leadership role and then pulled me

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BACUS N • E • W • S

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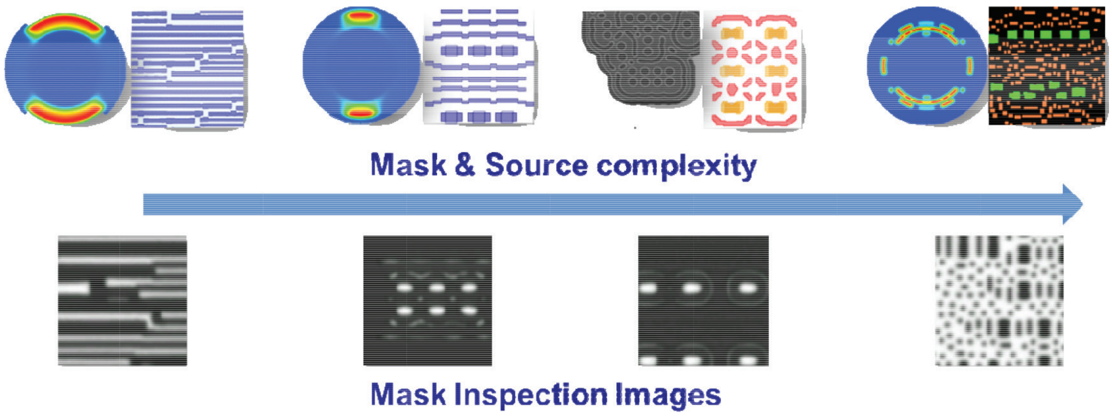


Figure 2. Complexity challenge of mask and source as design node shrinking.

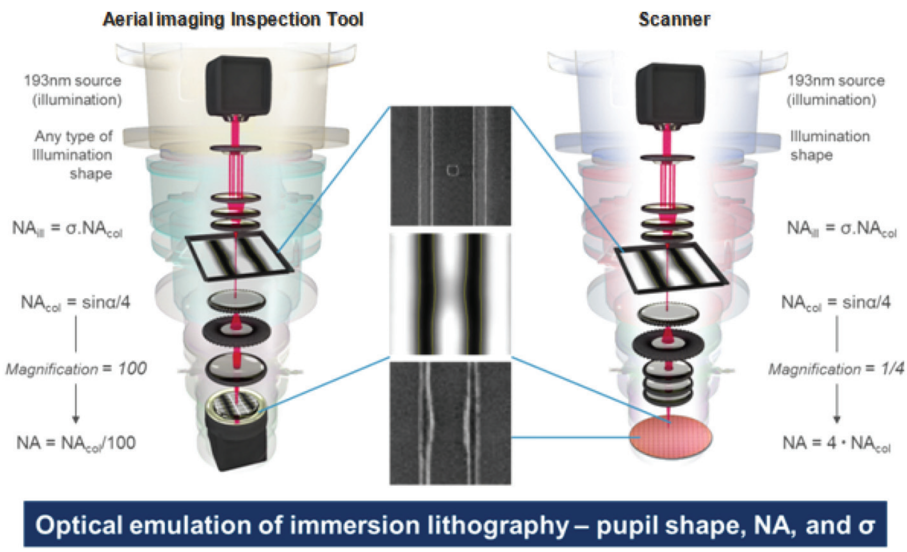


Figure 3. Optical emulation of immersion lithography for mask inspection.

1. Introduction

Industry roadmap is based on continuous half pitch reduction as show in Figure 1. As design rules continue to shrink towards sub-20 nm, the semiconductor manufacturing processes have been increasingly challenged. Optical lithography has been still lasting for mask production due to delays of EUV lithography. However, the resolution of DUV lithography approaches its limitation: Image contrast and MEEF are closer to their limits. For sub-20nm node masks the formerly used RET are not enough to provide the required process window. Therefore two practical techniques of the computational OPC schemes such as Inverse Lithography Technology (ILT) and Source Mask Optimization (SMO) are being studied.

Sub-20nm node masks including these technologies are very difficult to fabricate because of many small feature which are near the limits of mask patterning process. Figure 2 demonstrates the increasing complexity for various cases.

The difficulties are not only in the patterning process but also in the mask inspection step, especially in High Resolution. By the reason of using high resolution imaging in the conventional inspection technology, it has given rise to intensify the difficulties of mask inspection on complex OPCs.[2] Thus, these masks require the pragmatic inspection method which is a combination of the high sensitivity on main features and reduced detection rates in Sub-Resolution Assist Features (SRAFs).

This paper describes current inspection technologies like as Aerial Imaging (AI) illumination and High Resolution (HR) for sub-20nm mask with complex SRAFs. The limitations of those method, as well as currently available technique of de-sensing SRAFs detection are discussed in Section 2. An advanced solution to overcome this critical issue with HR inspection is demonstrated in Section 3 and summarized in Section 4.

2. Current Inspection Methods for ILT/SMO

2.1 Experimental inspection modes

The investigated inspection mode in this paper is Die-to-Die (D2D). In D2D two optical images are captured by the scanner of the inspection tool on two adjacent dies. Then two images are compared in order to find differences between the inspected image and the reference image. Some of these differences are strongly identified as either valid defects or nuisances on SRAFs. On the other hand, as knowing pattern information from database during inspection on DB method, it is easy to apply a selective de-sensing capability of SRAFs. All these ideas are based on maintaining high sensitivity on main features and giving low sensitivity on SRAFs simultaneously possible.[8]

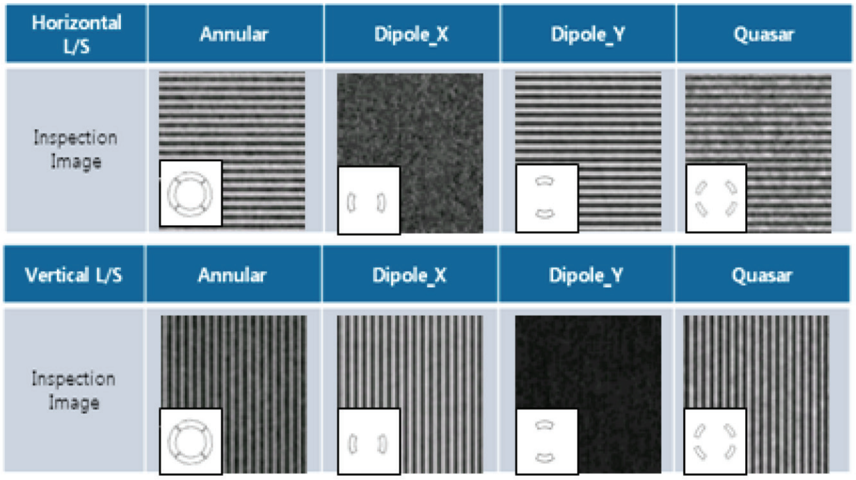


Figure 4. Different aerial images using various apertures.

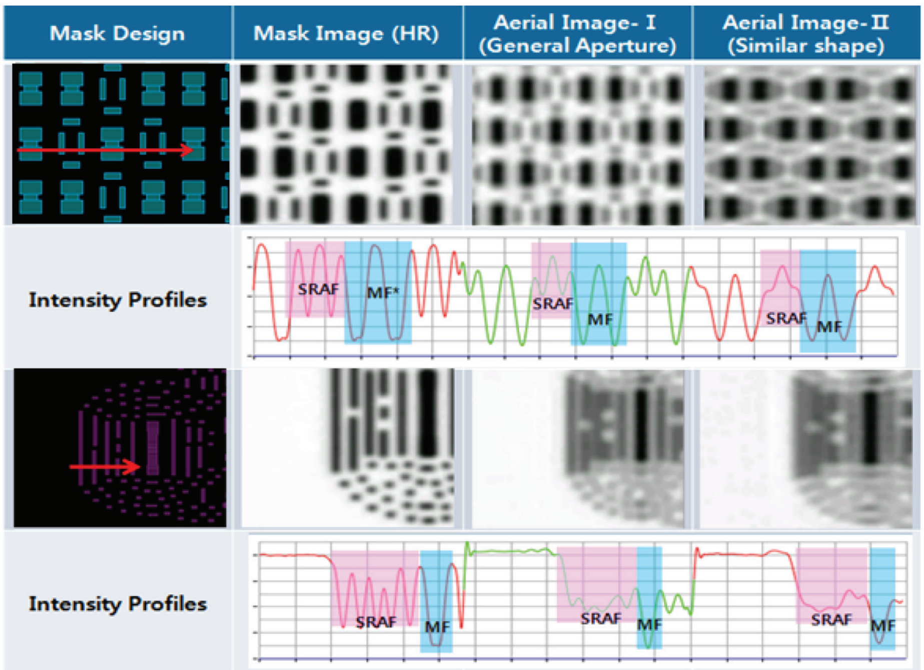


Figure 5. Intensity profiles of MFs and SRAFs in HR and AI with SMO-like and optimized aperture.

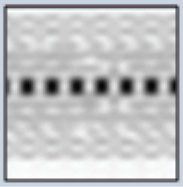
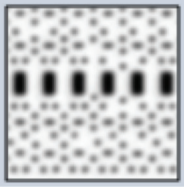
We experimented with two significant illumination modes which are using AI and HR for reducing nuisance defects on SRAFs in D2D mask inspection.

2.2 Aerial imaging inspection for ILT/SMO

Figure 3 shows the optics of AI inspection is similar (to some extent) to the ArF scanner. As a result of having vastly similar optical paths there is a noticeable parallel with between both AI inspection images and wafer level images shown in Figure 4. This enables focusing on detection of wafer printable defects (more practical) and increasing detectability for high MEEF area (HOT SPOT). It also provides different images according to aperture shapes (See Figure 4). AI inspection is much more generous to aperture shapes than HR inspection.

To understand intensity profiles for SRAFs according to inspection mode, we installed two aerial apertures such as the real SMO-like and the optimized in the inspection tool. Figure 5 shows the analysis of two patterns as found by HR inspection and AI inspection with SMO-like and general apertures. Looking at SRAFs and main features (MFs) intensity profiles, it is obvious that SRAF signal in both aerial images are significantly lower than HR images. This difference makes AI inspection more pragmatic for ILT/SMO masks. Then we also evaluated that AI inspection is available to optimized aperture which is generalized from several SMO apertures as well as using SMO-like aperture. It shows more reliable (lower) signal on SRAFs, yet the optimized aperture is also able to support SMOs.

Table 1. Comparison of AI and HR inspection results on ILT mask.

	Aerial Imagining	High Resolution
Sensitivity	Production settings	De-sensing required
Nuisance Defects	8	52
Defects on MF (Critical)	11	11
Defects out of MF (non-critical)	8	20
SRAF image example		

2.3 High resolution inspection for ILT/SMO

The achievement of high detectability to ensure better mask quality and efficient mask processing monitoring is the major goal of mask inspection. That is why HR inspection is surely needed for mask manufacturing.

As was previously reviewed, SRAF features are susceptible to writing process issues, and a high defect rate is expected to be picked up on such locations. Even small variation in SRAFs can result in a high difference. Such cases are real mask defects, but are of less importance, as the writing limitations on SRAFs is known, and its impact on mask yield is negligible.

Since HR inspection has high sensitivity on SRAFs as well, it can detect unwanted nuisance defects. For that reason inspection technology in critical patterns like as complex OPC structures requires a new function at HR inspection.

Table 1 shows the inspection performance between AI and HR on sub-2X ILT/SMO mask.

In this comparison, AI inspection provides inherent SNR attenuation due to the designed characteristic of SRAFs. This detection reduction of SRAF nuisance is achieved without compromise on the critical defects on main features. HR inspection covers all defect sensitivity needs, yet suffers from extra nuisance.

With the inspection challenge in hand, we tried to apply loose detection sensitivity on SRAFs, while maintaining tight sensitivity settings on all other patterns (i.e. printing pattern, background). In such an approach the slight variation of SRAFs morphology will be de-sensed. The segmentation between SRAFs and other patterns is done by taking advantage of the optical characteristic attributes. For example, the optical cutoff frequency and the optical Point Spread Function (PSF) are used to determine the amount of pixels that will have interaction with the photons scattered from a sub resolution feature (See Figure 6). The algorithm uses a unique relation between the intensity of the patterns, as it is being imaged through the tool optics and a priori knowledge of the pattern characteristics along with the intensity variations over the SRAF pattern.

When challenged with aggressive ILT masks (model based OPC), the result of this current SRAF identification algorithm was found to be in sufficient, as the basic assumption of separation in intensity and its variation did not allow for a clear division of SRAFs from other patterns. This result is achieved with the reduced sensitivity for SRAF's defects using newly developed SRAF De-sensing algorithm that is discussed in next section.

3. Advanced SRAF De-sensing High Resolution

3.1 The new SRAF de-sensing algorithm

Motivated by these observations, the HR D2D inspection flow was enhanced with an improved algorithm that is able to divide the SRAFs from the entire images. Since SRAF elements can be identified according to their width and specific intensity values, the new and advanced SRAF algorithm is based on the principle of identifying local maxima or minima ("Hill" or "Valley" shaped intensity values) of a certain predefined width on an image. Based on these SRAF identification map is built, allowing control of the sensitivity of the detection on different areas.

This newly-developed algorithm has powerful capability to separate ILT patterns from the original image population. A special set of morphological operators is applied the reference image to outputting an image in which local maxima and minima correspond to the SRAF elements. This image is furthermore analyzed to yield the SRAF identification map.

Figure 8 shows that the advanced SRAF de-sensing algorithm has robust results of all kinds of ILT patterns. These separated SRAFs are marked with Red at the ends and Green at the interiors of SRAFs.

3.2. Comparison of AI and HR with new SRAF de-sensing algorithm

It is confirmed that both inspection methods can detect printable defects. Current HR inspection has high detectability, but low inspectability is shown in ILT masks. Eventually this advanced algorithm enables to apply higher sensitivity on MFs than current HR inspection for that reason of low nuisance on complex SRAFs as shown in Table 2.

4. Conclusion and Future

Optical lithography trend leads to introduction of new RET methods such as ILT/SMO masks. The effort to fabricate ILT/SMO masks makes an increase in not only process difficulties but inspection challenges. There is more consideration of choosing the pragmatic inspection mode between aerial imaging inspection and high resolution inspection.

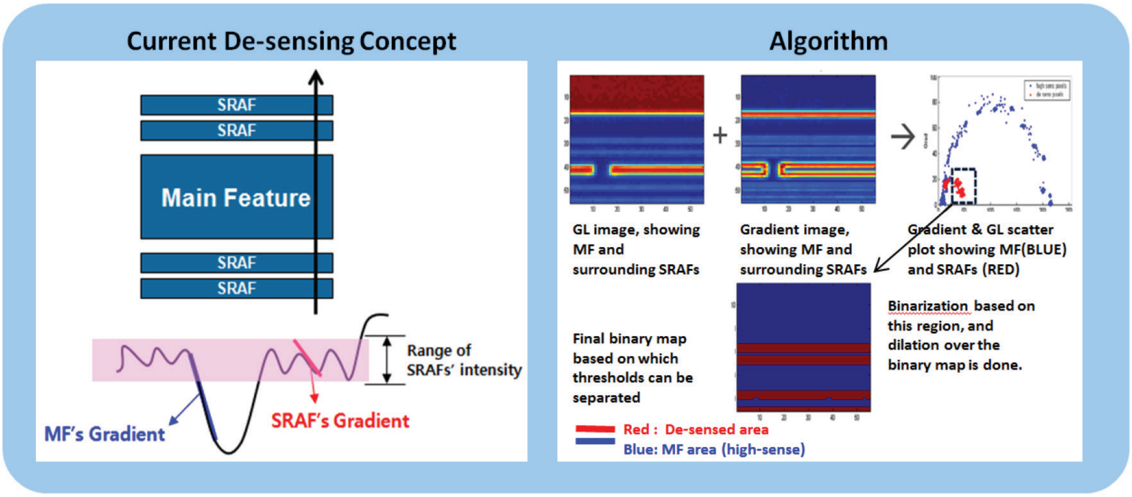


Figure 6. Current SRAF De-sensing algorithm flow in HR inspection

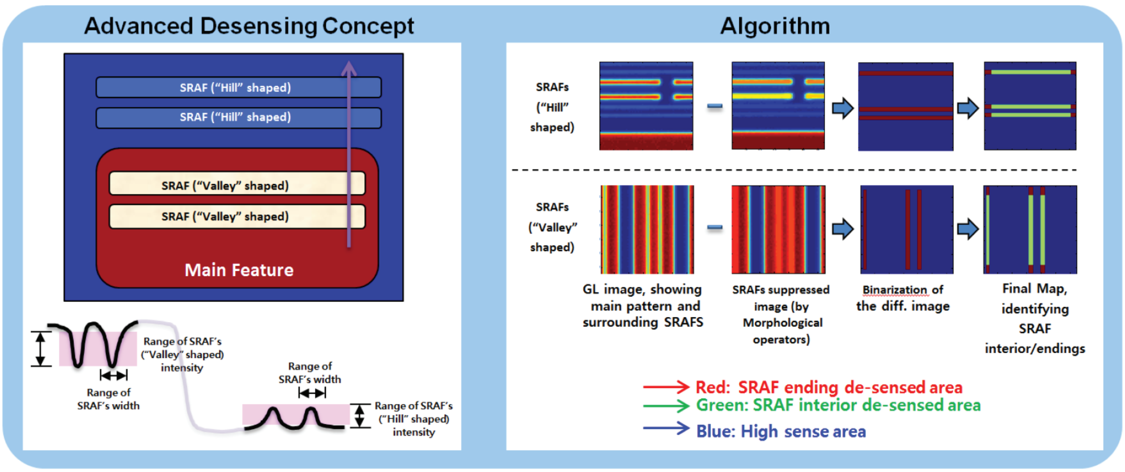


Figure 7. Advanced SRAF de-sensing algorithm flow in HR inspection.

AI inspection provides such a good sensitivity of catching various defects that could influence wafer results and the best inspectability of complex OPC patterns. HR inspection has a strong enough detectability in mask process monitoring to detect all defect types. However, there is a big burden of high false alarm on ILT/SMO masks due to aggressive OPCs. In 2Xnm node, current de-sensing algorithm uses the simple relation of intensity to patterns because of segmentation between SRAFs and others, but for all that it has suffered the separation of SRAFs from the original patterns in

ILT/SMO masks. That is why we have developed the advanced algorithm in HR inspection which has the higher detectability with low false alarms on those masks. In future work we continue to investigate all capabilities of both advanced HR and AI inspection to prepare for more complex ILT/SMOs era.

5. Acknowledgment

The authors would like to thank to the following institution and individuals Mask Inspection Part Members and Hye Wook Jang at Samsung Electronics Co. provide analysis data and technical feedback in this evaluation. We also would like to give acknowledgement of Applied Materials: Ziv Parizat, Boaz Cohen, Suk Woo Lee support the aerial application and the new algorithm development.

6. References

[1] Pang, L., Peng, D., Tam, A., et al, "Computational inspection applied to a mask inspection system with advanced aerial imaging capability", **Proc. SPIE 7638** (2010).

[2] Pang, L., Xiao, G., Tolani, V., et al, "Considering MEEF in inverse lithography technology (ILT) and source mask optimization (SMO)", **Proc. SPIE 7122** (2008).

[3] Xiao, G., Cecil, T., Pang, L., et al, "Source optimization and mask design to minimize MEEF in low k1 lithography", **Proc. SPIE 7028** (2008).

[4] Pang, L., Liu, Y., Dam, T., et al, "Inverse Lithography Technology (ILT), What is the Impact to Photomask Industry?", **Proc. SPIE 6283** (2006).

[5] Kim, B.G., Suh, S.S., Xia, G., et al, "Inverse Lithography Technology (ILT) Mask Manufacturability for Full-Chip Device", **Proc. SPIE 7488** (2009).

[6] Baik, H.J., Chung, D.H., Sagiv, A., et al, "Practical application of aerial imaging mask inspection for memory devices", **Proc. SPIE 7028** (2008).

[7] Sagiv, A., Mangan; S., et al, "What you see is what you print: aerial imaging as an optimal discriminator between printing and non-printing photomask defects", **Proc. SPIE 7028** (2008).

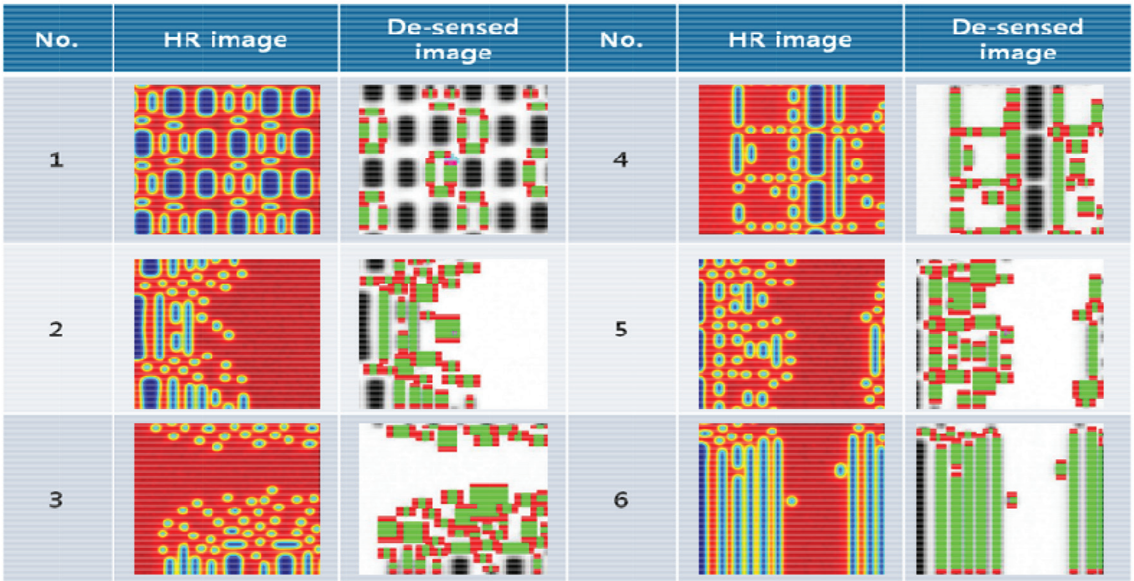


Figure 8. HR images of ILT patterns and their de-sensed regions by the new algorithm.

Table 2. Comparison of AI and HR inspection (with new algorithm).

	Detectability (Wafer printable)	Detectability (all defects)	Throughput	False rate
Aerial Imaging	😊 😊	😊	😊 😊	😊 😊 😊
Current HR for ILT/SMO mask	😊 😊	😊 😊	😊	😊
New HR algorithm for ILT/SMO mask	😊 😊 😊	😊 😊 😊	😊	😊 😊

[8] Han, S.H., Park, J.H., Kim, D., et al, "A pragmatic approach to high sensitivity defect inspection in the presence of mask process variability", **Proc SPIE 6730** (2007).

[9] Han, S.H., Cho, W., Chung, D.H., et al, "Inspection of complex OPC patterns for 4x node and beyond", **Proc SPIE 7488** (2009).

Editorial

continued from page 2

into the Bacus management team. Suddenly I found myself tasked with acting as the BACUS conference chair and now, President of BACUS. I can only thank Frank for this effort.

As can been seen in the illustration, mask makers are in the bulls-eye of the semiconductor industry. The market size is small relative to the overall semiconductor and consumer electronics markets yet masks are a critical element that enables these industries. It is clear from the presentations and participation at mask conferences this year that our industry continues to be strong, in spite of the pricing pressures and consolidation that has occurred.

During my career I moved from being an outsider to a true mask industry insider. The reticle business continues to be my focus and is in the 'bulls-eye' for me as well. I want to help drive a successful mask marketplace in the future.

The experience this year was challenging, yet enjoyable and successful. All of the technical conferences provided excellent value to the industry. The combination of the Scanning Microscopies conference with the Bacus Photomask strengthened and enhanced the event and we plan to continue this in the future. I look forward to the next year(s) working with the SPIE team of Brian, Pat, and Bacus steering committee. Thanks to all for your confidence in me and I hope to meet your expectations.

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Industry Briefs

Intel Hits Revenue Record in 2014; PC and Tablet Groups Exceed Goals

Jessica Lipsky, EEtimes

Intel reported better than expected financial results and record-breaking full year revenue of $55.9 billion.

Intel 2014 revenue grew 6% while operating income rose 29% to $15.3 billion and net income hit $11.7 billion. Intel generated approximately $20.4 billion in cash from operations, paid dividends of $4.4 billion, and used $10.8 billion to repurchase 332 million shares of stock. Fourth quarter revenue was $14.7 billion and operating income was reported at $4.5 billion, with a net income of $3.7 billion.

The Data Center Group reported revenue of $14.4 billion, up 18% year-over-year, while the newly formed PCG reported revenue of $34.7 billion, up 4% percent from 2013. Revenue from the Mobile and Communications Group, which merged into PCG last year, dropped 85% to $202 million.

Other highlights from the fourth quarter earnings call include:

- The Internet of Things Group reported revenue of $2.1 billion in 2014, up 19% from 2013. Q4'2014 revenue was $591 million, up 12% sequentially and 10% year-over-year.
- Fourth quarter revenue from the software and services operating segments was $557 million, flat sequentially and down 6% from 2013. Full year revenue was up 1% to $2.2 billion.
- R&D plus MG&A spending will reach approximately $20 billion in 2015, largely due to existing research and development costs from its Axxia Networking buy.

TSMC Reports Record Quarterly Income; Analysts Turn Negative on TSMC Outlook

Alan Patterson, EETimes

TSMC said net income soared 79 percent from a year earlier to NT$79.99 billion (US$2.51 billion), a new quarterly record. The company also reported record full-year earnings, surging 40 percent to NT$263.9 billion. TSMC raised its capital expenditure budget for 2015 to US$11.5-12.0 billion, an increase of 11.5-20.0 percent compared with 2014. The company said volume production for 16 nm FinFET is on schedule for the second quarter of this year.

However, the analysts switched to a more negative outlook for TSMC. According to Mehdi Hosseini, Susquehanna Financial Group analyst, TSMC will face stiff competition to its 16 nanometer chips from Samsung's 14 nm offerings. Samsung's progress with yield improvement will add to losses in TSMC's share of the business from Apple, according to BNP Paribas analyst Szeho Ng in a January 15 report. Adding to concerns about the outlook for TSMC, sales of smartphones are likely drop from 26 percent in 2014 to 12 percent this year, according to market research firm International Data Corp.

Samsung and Globalfoundries Reportedly Win Majority of A9 Orders

Josephine Lien, Jessie Shen, DIGITIMES

Samsung Electronics and Globalfoundries have secured a combined 70% of orders for Apple's A9 processors with their 14nm FinFET technology, according to industry sources.

Samsung plans to produce 30,000-40,000 12-inch wafers monthly to meet demand on its 14nm process node, with the demand from both Apple and Samsung's own handset division. Samsung will also be building its next-generation Exynos processor on its own 14nm process. Globalfoundries will be used as a backup fab by Samsung for the manufacture of Apple's 14nm A9 chips, with the availability of production capacity estimated at 20,000-30,000 wafers monthly.

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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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Calendar

2015

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