PHOTOMASK

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WEREWOLF – Sensitivity optimization for early 7 nm EUV masks using an optical 19x nm inspection system

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ABSTRACT

EUV (Extreme Ultraviolet) lithography is one of the key enabling techniques for imaging 7-nm node and beyond wafer technologies. To ensure mask quality levels will support High Volume Manufacturing (HVM), all "defects that matter", must be identified and screened out before shipment to the wafer fab. Mask defects that matter are the ones that print during exposure at 13.5 nm wavelength. To support EUV development and production schedules, mask defectivity must be reduced to be at or near the optical defect levels. This task is complicated by the fact that actinic EUV mask inspectors are not currently available. In the absence of these EUV inspection tools, all available methods for detecting and characterizing defects must be deployed.

Based on extensive deployment and on its record for reasonable throughput, 19x nm wavelength inspection is one of the strongest candidates available today for the initial EUV mask inspection approach.

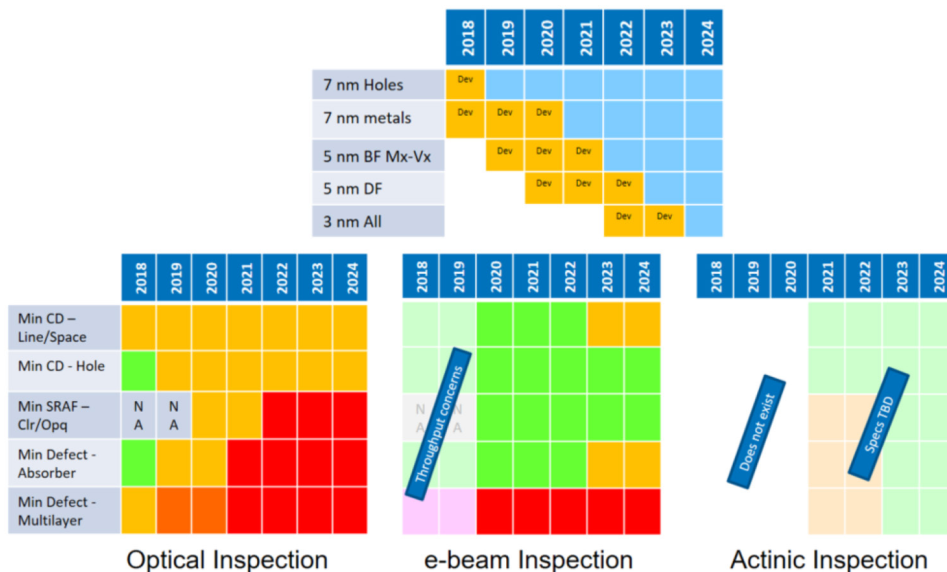

Figure 1. Availability of EUV mask inspection equipment, versus technology roadmap.

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EDITORIAL

Mask Industry: Up, and To the Right!

Aki Fujimura, CEO, D2S, Inc.

As reported in the Industry Briefs section of the October 2018 edition of this newsletter, SEMI reported recently that the overall mask market increased to $3.75B in 2017, a 4.1% compounded annual growth rate (CAGR) for 3 years ending 2017. And, according to two new surveys conducted by the eBeam Initiative and presented last month at the SPIE Photomask Technology Conference in Monterey, CA, mask makers reported a significant increase in mask output this year as compared to last, and industry leaders predict the market growth will continue.

The eBeam Initiative surveys were conducted over the summer, prior to the recent news about capital expenditure reductions in semiconductor manufacturing. However, the two surveys, taken together, do still paint an optimistic picture for the future growth of semiconductor manufacturing – the line on the growth chart is up and to the right. The eBeam Initiative mask makers survey respondents – the same 10 captive and merchant photomask manufacturers who participated in last year's survey – reported a 27% overall increase in mask output this year as compared to last. Increases were reported in numbers of masks produced at every ground rule, but ≥5nm and <7nm, ≥16nm and <22nm, and ≥65nm and <90nm were particularly pronounced in percentage increases year over year. Respondents reported that lasers wrote 74% of the masks they produced this past year. Overall mask yields have remained steady at 94% over the last two years.

In addition to the increase in the total number of masks written, the average write time required to write masks also increased year to year. Average write time for VSB writers increased from 6.8 hours in the 2017 survey to 8.3 hours in 2018. Average write time for laser writers increased from 1.8 hours to 2.1 hours. Taken together, the total demand for mask writers of every type increased significantly year over year. Mask data volume average also went up substantially for both. Average data volume for VSB writers went up from 0.94 to 1.23 TBytes for VSB writers and from 8 to 19 GBytes for laser writers. Since data volume correlates with inspection and other processing times as well, the overall demand on mask manufacturing equipment increased significantly year to year.

Mask makers did not note an improvement in mask turnaround time. As in previous years, respondents reported that leading-edge ground rules have substantially longer mask turnaround times than the previous generation. Ground rules above and including 130nm have an average turnaround time of 3.2 days, while those below and including 7nm need 11.7 days.

Separately, the eBeam Initiative also conducts an annual industry perceptions survey. Started in 2012, this opinion-based survey is sent to industry luminaries each year to gather the best predictions of industry trends. When asked if the CAGR of 4.1% shown in the SEMI study could be maintained in the future, 95 percent of respondents predicted that the CAGR for overall mask market will be at least 4.1% between 2018 and 2020; more than 50 percent of respondents predicted the CAGR would be higher than 4.1%.

While reported EUV masks still represent a very small percentage of overall mask production, the number of EUV masks reported doubled this year (2185) from last year (1041). The perceptions survey showed 82 percent of respondents predicted that EUV lithography will be used in high-volume manufacturing by 2021, while only 1 percent of respondents predicted it will never happen.

The perception survey showed similar optimism about the adoption of multi-beam mask writers (MBMW): 82 percent of respondents indicated that they believe that MBMW will be used in high-volume manufacturing by the end of 2020.

The time-bound quest for the next technology node requires simultaneous advances in the state-of-the-art in human creation in physics, chemistry, material science, mechanical engineering, computer science and high-performance computing, including deep learning. It is a large-scale team effort involving many, many people, companies, research organizations, universities and government agencies of so many different disciplines, bound together by the common mission to get the next node working on time. At the SPIE Photomask Technology Conference, we get to see the best-of-the-best in human capability. It is great fun to be able to be in the middle of all this action. And even better when we see that growth line going up and to the right!

To view slides that summarize all of the data collected by these surveys go to: **http://www.ebeam.org/docs/eBeam-Perception-Survey-2018.pdf and http://www.ebeam.org/docs/eBeam-Mask-Maker-Survey-2018.pdf**

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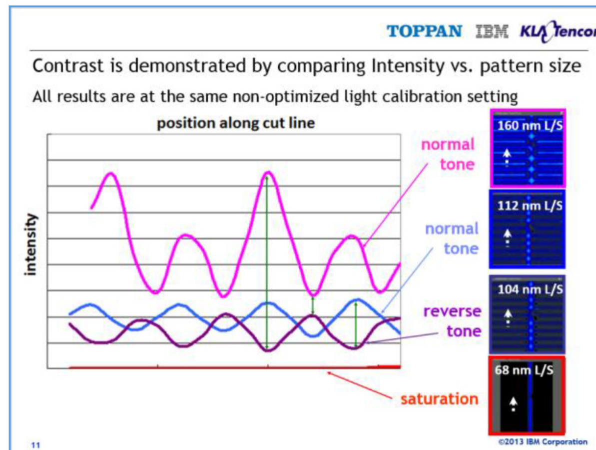


Figure 2. Contrast, tone reversal and saturation as a function of defect intensity and pattern size. (Evaluation of non-actinic EUV mask inspection and defect printability on multiple EUV mask absorbers. K. Badger, et al, 2013 Photomask Japan).

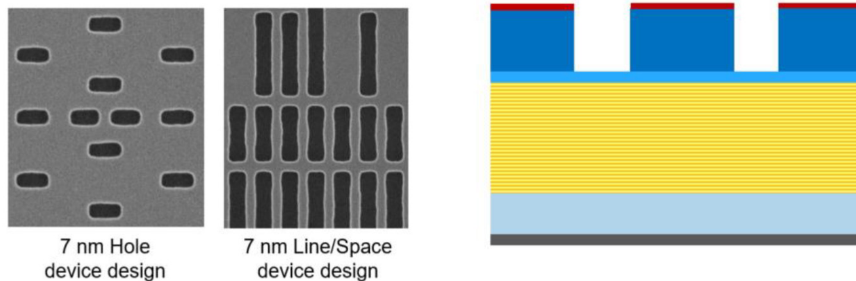


Figure 3. WEREWOLF PDMs 7 nm hole and line/space designs and substrate configuration.

However, there are several key challenges with 19x nm optical inspection of EUV masks. Aside from the documented challenges of using a non-actinic wavelength, a key challenge is that the defect sensitivity varies based on pattern sizes and defect types and therefore, a wide range of pattern sizes and defect types need to be used to optimize inspection sensitivity. Through a variety of evaluations on simple test patterns, it has been confirmed that a combination of multiple focus offsets and polarization settings enables adequate sensitivity to meet early sensitivity requirements for 7 nm EUV production masks. As the result, focus offsets and polarization settings could be optimized to successfully develop new inspection recipes that could meet a target defect criteria with multi-pass inspection.[1]

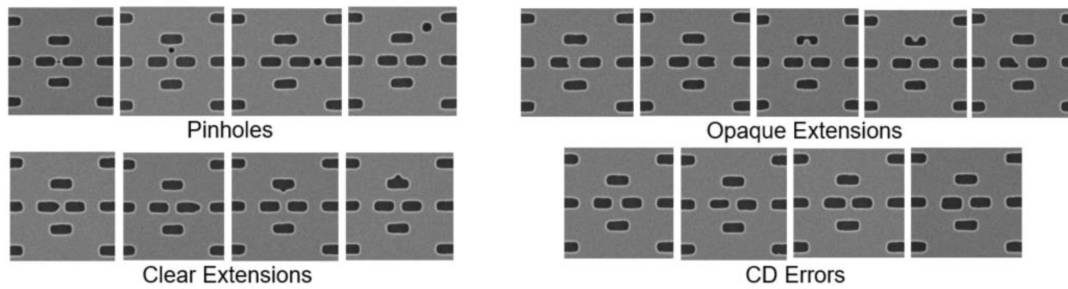
In this study, we will show inspection results of programmed defect macros (PDMs) based on actual EUV device constructs. Then, it will be discussed whether a combination of multiple focus offsets and polarizations is an effective approach to increase defect sensitivity on device patterns through the analysis of PDMs. We will demonstrate how inspection parameter optimization can be done to tailor 19x nm inspection to EUV device designs and what defect sizes and types are detectable with a 19x nm inspection system to assess capability for meeting the 7nm node development and production requirements.

1. Introduction

As technology evolves, advanced imaging techniques become more important to resolve smaller and smaller features on wafer. One of the most promising approaches to resolving these images for 7 nm node and beyond is EUV (Extreme Ultraviolet) lithography. Producing defect free masks for this advanced technology approach is complicated by the fact that the availability of 13.5 nm wavelength scanners has far surpassed the timing of 13.5 nm wavelength mask inspection equipment.

Figure 1 shows an estimation of the timing and capability for each of the three inspection candidates for EUV mask inspection: 19x nm Optical, e-beam and actinic. While the industry awaits the arrival and integration of actinic mask inspection capability, measures must be taken to determine what is possible on *currently available* equipment[1-3]…specifically, what levels of inspectability and defect sensitivity can be achieved on 19x optical and e-beam inspection equipment. 19x optical inspection has a well-established history and reputation for sensitivity and inspectability for optical masks built on various attenuators and for critical dimensions through 7 nm node—at an acceptable rate of throughput[4-7]. Over time, extensive optics and algorithm improvements have been implemented on 19x nm inspectors to improve EUV mask inspectability and sensitivity[8-10], but the question remains as to whether they are capable of finding all wafer printable defects in both the absorber and multi-layers. In Figure 1 below, it is apparent that 193 nm optical inspection will become less effective with the introduction of assist features, so at best, may be usable at a somewhat reduced sensitivity through 2019, and potentially through 2020 if assist feature desense is acceptable. E-beam inspectors are specifically being introduced for the inspection of EUV masks, and provide an advantage over optical inspection equipment

Defects of Interest – 7 nm Hole Design



Defects of Interest – 7 nm Line/Space Design

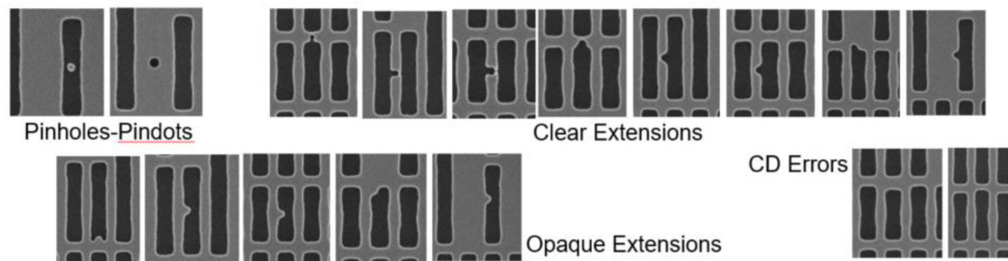
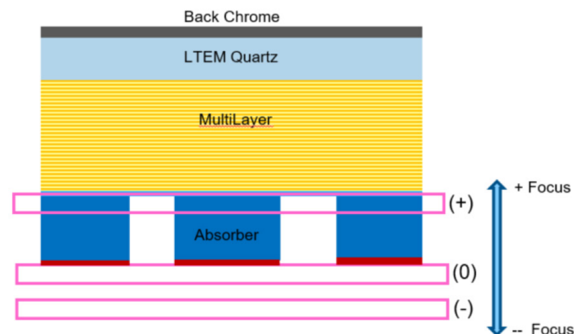


Figure 4. WEREWOLF PDMs - Defects of Interest.



Focal Planes

- ZERO focus offset is focus at the surface of the Absorber
- Positive (+) focus offset is focus TOWARD the Multilayer
- Negative (-) focus offset is focus AWAY from the Absorber

Figure 5. Focal Planes definition.

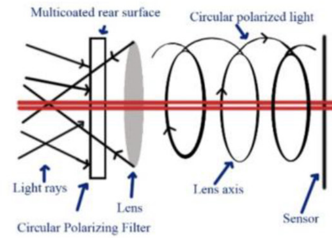
in that they are able to achieve higher defect sensitivity on smaller critical dimensions due to the smaller beam size. Unfortunately, this improved capability typically comes at the cost of very long inspection times and low throughput, charging issues with the black border, and the total inability to see into the multi layer. Similar to the 19x nm inspectors, additional work is also required relative to the detection of all wafer-printable defects by e-beam inspectors. On the other hand, Actinic database pattern inspection, by its very nature, is the best solution for detecting wafer-printable defects…except for the fact that it is not currently available.

It has become evident that EUV masks will require more advanced approaches to mask inspection. The absence of actinic inspection capability is compounded by the fact that the EUV substrate is not transmissive (due to the chrome backing layer), and therefore must be inspected only with reflected light. A second complication is the nature of the substrate itself, consisting of the LTEM (Low Thermal Expansion Material) substrate, backside conductive layer, front-side reflective stack of 40 pairs of Mo/Si bilayers, a Ru protective cap, and the Ta-based absorber material. Defects on…or in, any of these layers could print on wafer. Again, actinic inspection is expected to see into all of these layers and provide sensitivity enough to achieve the detection of wafer-printable defects, however, current 19x nm wavelengths are

Polarization *(Source: https://opentextbc.ca/physicstestbook2/chapter/polarization/)*

Circular Polarization for Hole Layer PDM

Circular polarization focuses the light rays in a circular motion toward the filter.



X-Y Polarization for Line/Space layer PDM

X and Y polarization done separately.

X or Y filter transmits only the component of the wave parallel to it's axis and reduces the intensity of any light not parallel to it's axis.

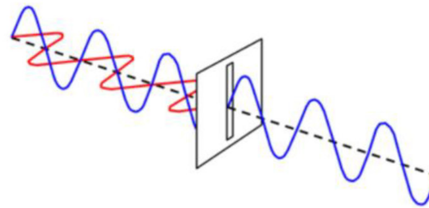
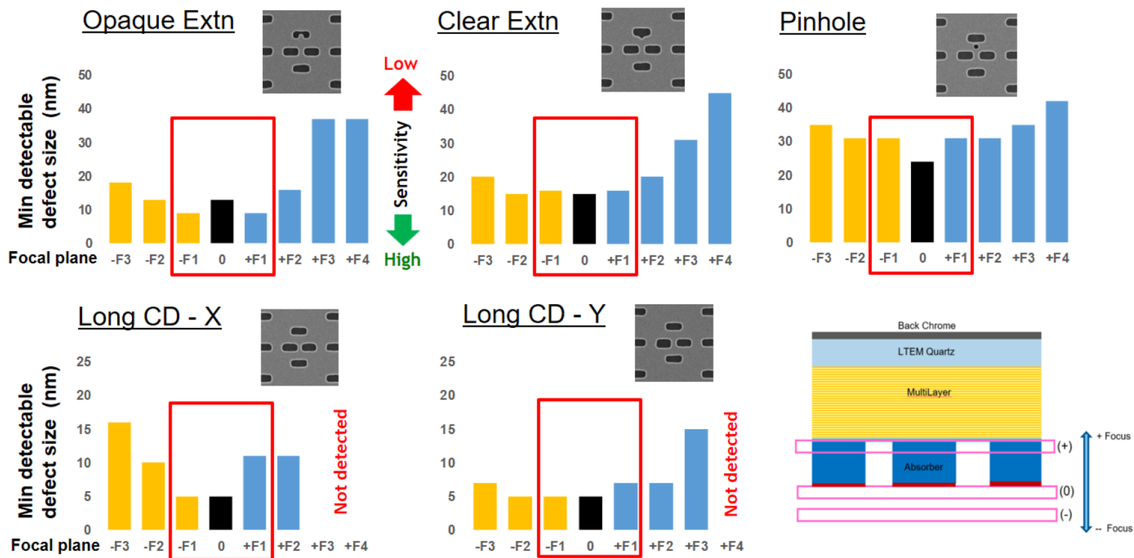


Figure 6. Polarization definition.

Min detectable defect size vs Focus with C-pol



Detectable defect size dramatically varies among focus planes

-F1, 0, +F1 are more sensitive than other focal planes for all defect types

Figure 7. Hole Layer PDM inspected with Circular Polarization and eight different focal planes.

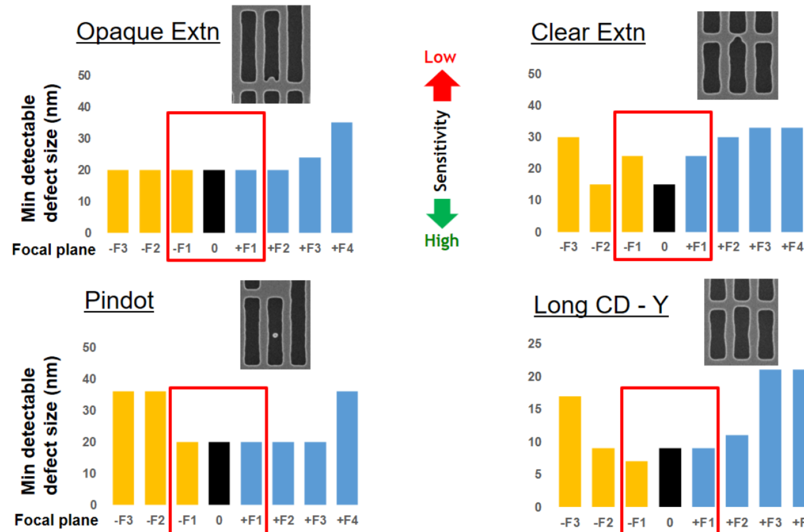
able to penetrate only the top 3-4 layers, and e-beam is not expected to penetrate the Mo/Si bilayers at all.

Considering the non-availability of actinic inspectors at this time, and the relatively recent introduction of e-beam tools that will require extensive evaluation and optimization, the focus of this paper will be on steps that may be taken on 19x nm inspection equipment to potentially improve the detection capability of absorber defects that may print on wafer.

2. Analysis of Present State

Before we begin this evaluation, let us first point out a few conflicts that exist between the 19x nm inspection wavelength and EUV material properties.

19x nm optical mask inspection requires at least 65% contrast between the absorber and the multilayer in order to achieve optimum sensitivity and inspection speed. The index of refraction for the 193 nm wavelength is not even close to that of EUV. The current absorber



Detectable defect size dramatically varies among focus planes

-F1, 0, +F1, have well-balanced sensitivity for all defect types

Figure 8. Line/Space Layer PDM – inspected with Circular Polarization and eight different focal planes.

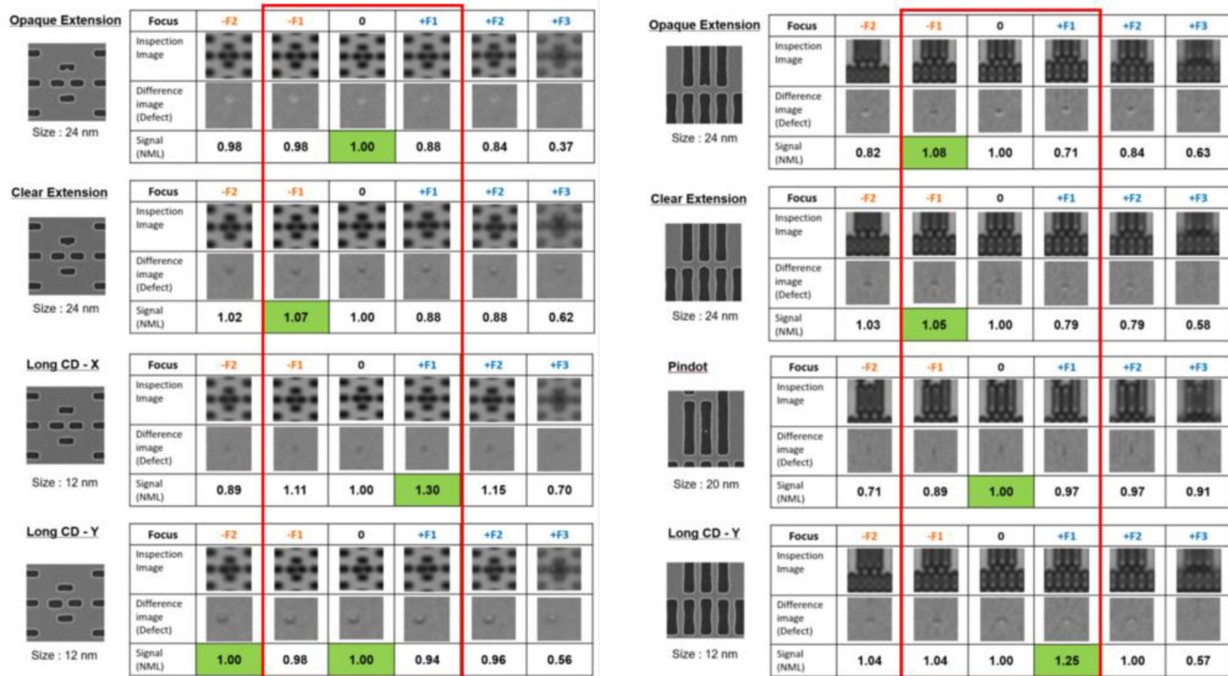


Figure 9. Impact of focus offset on defect signals (Hole layer - left, Line/Space - right).

stack is approximately 37% reflective at 19x nm wavelength, while the multilayer is approximately 60% reflective. This results in a contrast of approximately 24% versus a target of 65%. In addition, Figure 2 demonstrates two optical phenomena at 19x nm wavelength: image tone reversal, which occurs at a specific image size and effectively lowers the intensity of the defect signal, and saturation or poor resolution, which happens near the 68 nm point.

In previous work, it was determined that reducing base pattern contrast is not the right solution toward the goal of maximizing defect signal, but rather, improved defect signals are better achieved through adjustments or combinations of focus and polarization[11]. These results confirm that no single polarization or focus setting is able to detect all of the defects, but that improved sensitivity can be achieved through a combination of polarization and focus settings.

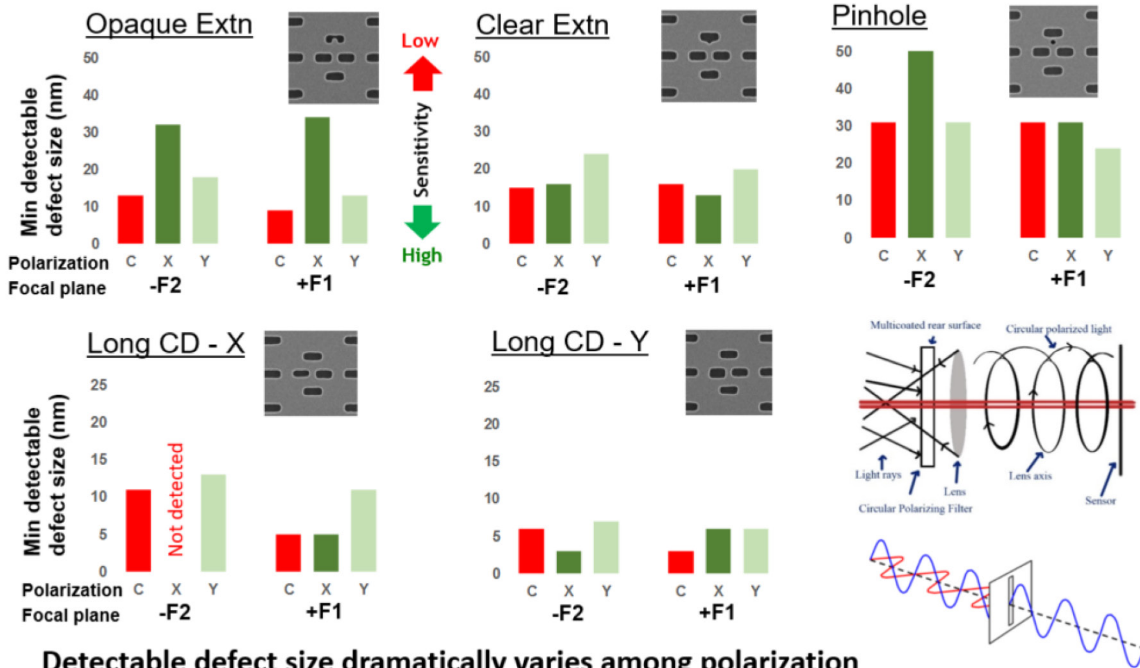


Figure 10. Inspection results for the Hole Layer PDM at the –F2 and +F1 focus settings, comparing Circular Polarization, X Polarization and Y Polarization.

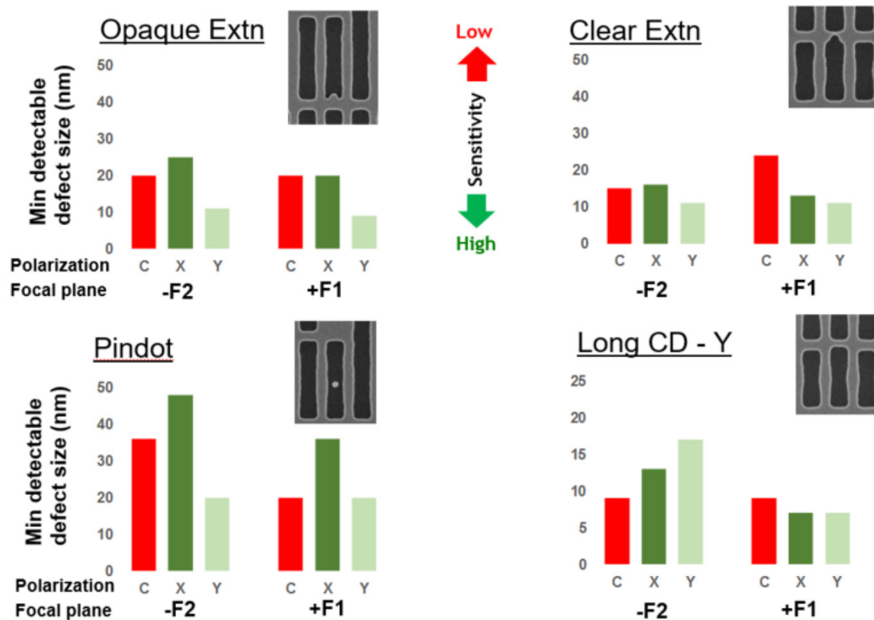


Figure 11. Inspection results for the Line/Space PDM at the –F2 and +F1 focus settings, comparing Circular Polarization, X Polarization and Y Polarization.

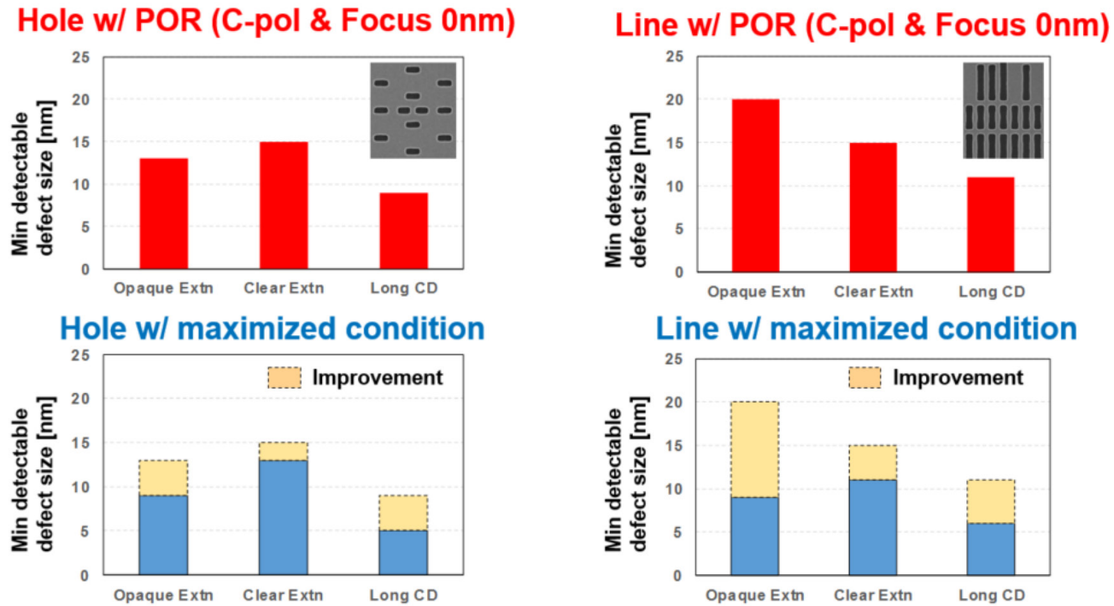


Figure 12. Single pass sensitivity versus multiple combinations of polarization and focus offsets.

3. Test Vehicles

Knowing that defect sensitivity can be influenced through a combination of polarization and focus settings, the primary goal of this evaluation was not only to verify how much improved defect sensitivity was possible, but to determine whether that improved sensitivity as adequate for *all* wafer printable defects on a 7 nm EUV product design. To achieve that goal, new programmed defect test macros (PDMs) were designed. That PDM is named WEREWOLF (World-class Euv REticle for Widespread Optimization, Learning and Feasibility study). WEREWOLF was designed to specifically understand absorber defect sensitivity and printability on actual 7 nm node product designs. Figure 3 provides a visual representation of the hole and line/space design types and substrate configuration. Figure 4 provides examples of the typical programmed defects available for analysis.

Multiple focus offsets and polarizations were used in this evaluation. As is traditionally done, best focus is defined as the surface on which the 19x tool produces the sharpest image profile for the absorber. As seen in Figure 5, for the purpose of this study, Zero focus is placed on the surface of the absorber, Negative focus is positioned *away* from the absorber, and Positive focus is positioned *toward* the Multilayer.

Figure 6 demonstrates the two types of polarization that were used in this study. Circular Polarization, or C-Pol is *generally* used for hole layers, and focuses the light rays in a circular motion toward the filter. X-Y Polarization are *generally* used for line/space layers. The X or Y filter transmits only the component of the wave parallel to its axis, and reduces the intensity of any light not parallel to its axis. For the purpose of this evaluation, both pattern types were inspected using both Circular and X-Y polarizations

4. The Impact of Focus and Polarization on Defect Sensitivity

The Hole layer PDM was inspected with eight different focus offsets, and with Circular Polarization. The eight focus offsets include best focus (denoted by 0), three negative offsets (denoted by –F1, -F2, -F3), and four positive offsets (denoted by +F1, +F2, +F3, +F4). All inspections used exactly the same defect sensitivity settings. The sensitivity results can be seen in Figure 7. As can be seen, the smallest detectable defect size changes dramatically with a fixed Circular polarization and varied focus. What is also clear, is that no *one* focal plane finds all of the smallest defect sizes, however the –F1, 0 and +F1 focal planes are more sensitive than the other focal planes tested. What is also implied is that all three of these inspections taken together—one at –F1 focus and the others at 0 focus and +F1 focus—are capable of finding the smallest detectable defects at the settings used for this 19x nm optical inspection. It is possible, that in order to achieve maximum sensitivity for the smallest detectable defects by type, multiple inspections at multiple focal planes may be required.

Even though Circular Polarization is typically used on Hole layer patterns, tests were conducted to look at Circular Polarization combined with multiple focus offsets on the Line/Space pattern as well. The same eight focus offsets were used. The sensitivity results can be seen in Figure 8. As with the Hole layer pattern, the smallest detectable defect size changed dramatically with a fixed Circular polarization and varied focus. In this case, the –F1, 0 and +F1 focus offset settings provide the best combined sensitivity for all defect types on the Line/Space PDM. Again, as was the case with the Hole layer PDM, maximum sensitivity for the smallest detectable defects by type was achievable with Circular Polarization combined with multiple focal planes.

Figure 9 demonstrates the impact of the different focal planes on defect signal for both the Hole layer and Line/Space layer PDM's. As can be seen, the defect signal varies slightly with focal plane, and

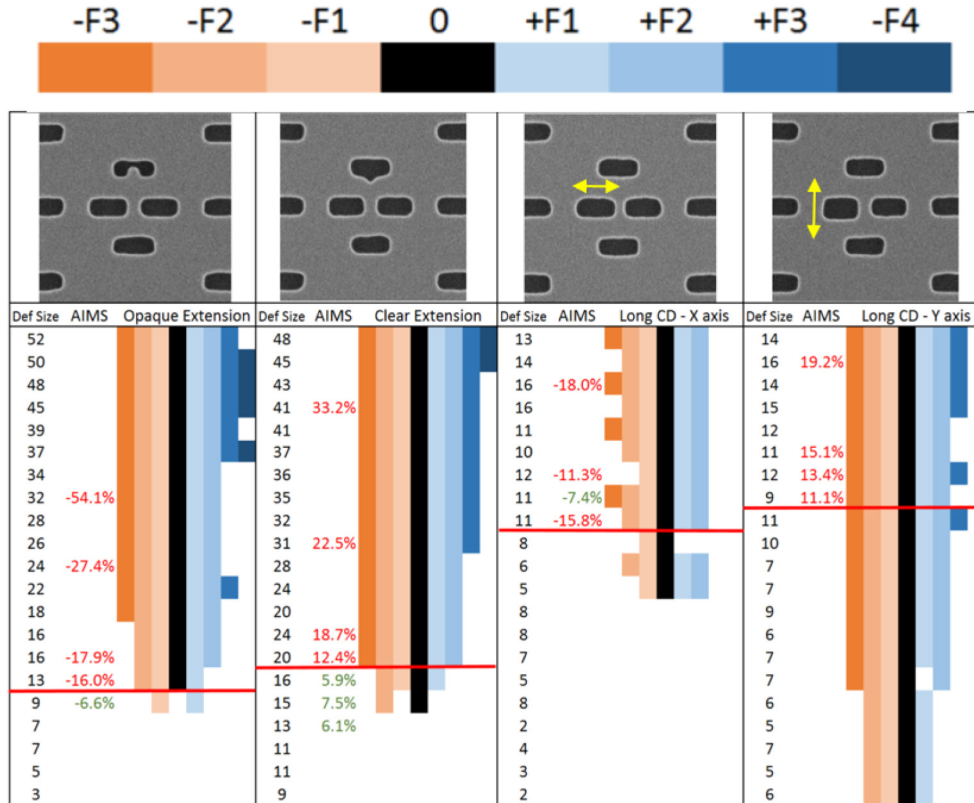


Figure 13. Detectability by focus offset and Circular Polarization versus EUV AIMS™ Printability.

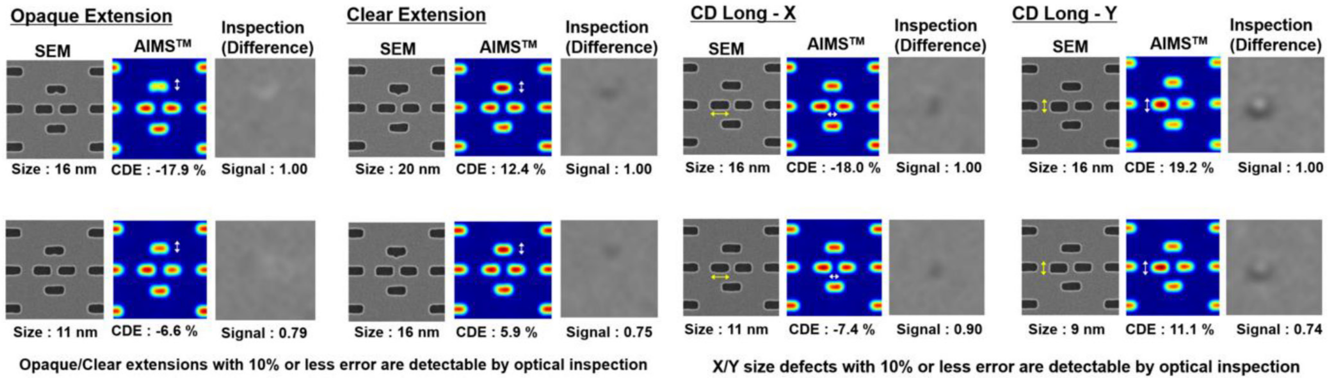


Figure 14. EUV defect signal and printability as a function of defect size.

for nearly all defect types analyzed, a combination of multiple focus offsets provide the best sensitivity.

The next phase of this evaluation was to determine if defect sensitivity could be influenced by changing the polarization. To that end, X Y Polarization, along with two of the original eight focal planes, was used to inspect both the Hole layer and Line/Space layer PDM's, and then a comparison was made to those same two focus settings from the Circular Polarization runs on both PDM's. Figure 10 provides the inspection results for the Hole Layer PDM at the –F2 and +F1 focus settings, comparing Circular Polarization, X Polarization and Y Polarization. The defect types evaluated are opaque and clear extensions, pinholes and oversized critical dimensions (X and Y).

For the Hole layer PDM, Circular polarization provided overall better sensitivity than X or Y polarization, however, what is interesting to note, is that the Y polarization on the Hole PDM provided better sensitivity results on *opaque* edge defects and the X polarization provided better sensitivity results on *clear* edge defects. For optimum sensitivity, combined inspections using all three of the polarizations provides the best sensitivity for these two focus offset settings.

Figure 11 shows similar results for the same three polarizations and focus settings on the Line/Space PDM. The defect types evaluated here are opaque and clear extensions, pindots and oversized critical dimension (Y axis only).

For the Line/Space results, the Y polarization provided better sen-

sitivity than the X Polarization, regardless of defect contrast, and it provided better sensitivity than the Circular polarization for all but one defect type on the –F2 focus offset (long CD). For optimum sensitivity, combined inspections for Circular and Y polarization provides the best sensitivity for these two focus offset settings. Note that if this pattern was rotated 90-degrees, we would expect X polarization to provide better sensitivity than Y polarization.

Figure 12 describes the overall take-away from the focus offset and polarization study…that using a single polarization and single focus offset will provide a certain level of defect sensitivity for EUV masks, however, using multiple focus offsets and polarizations in combination with each other can improve overall sensitivity as small as 15 nm for opaque and clear extensions, and as small as 7 nm for critical dimension errors.

It should be noted that the results depicted in Figure 12 reflect *all* of the focus offsets and polarizations combined (Circular Polarization, X Polarization, Y Polarization, -F3, -F2, -F1, 0, +F1, +F2, +F3, +F4 focus offsets) with all inspections run at higher-than-normal sensitivity settings. Obviously, this is not feasible in a high-volume manufacturing mode for two reasons…first, it represents up to 24 inspections on the same mask, and second, at higher-than-normal detector settings, there will undoubtedly be excessive nuisance detections in addition to the real, programmed defects. What *is* feasible, however, is determining the exact wafer-printable size by defect type, and then determining a fewer number of focus offset and polarization combinations…*and* optimized detector settings, that will come closest to achieving level of sensitivity required to detect them.

5. Printability Results

We began this study to determine if it was possible to extend the capability of existing 19x nm optical inspection equipment to at least improve the ability to detect wafer printable absorber defects. We have demonstrated thus far that it is indeed possible to *improve* overall defect sensitivity by combining multiple polarizations and focus offset settings, however, the question remains—can we realize enough improvement to carry us over to the next generation inspection capability? To answer that question, we engaged in two printability studies: one using EUV simulation, and the other, using EUV AIMS™.

Figure 13 provides the EUV AIMS™ printability results for the Hole Layer PDM, on the Opaque Extension, Clear Extension, Long CD X and Long CD-Y defect types. To reiterate, these defects were inspected at eight different focal planes, using high sensitivity defect detectors. The red lines represent the 10% CD error on wafer target for each defect type. As demonstrated in Figure 12, several of the focal planes are able to detect wafer printable defects. In some cases—specifically for the Long CD-Y defect type—the inspection was able to detect defects significantly smaller than the 10% CD print line. This additional sensitivity provides room to desense to more inspectable detectors for this defect type without losing the required sensitivity to detect printable defects.

One thing to note is that the *linear* defect sizes for the edge and CD defects are smaller than 20 – 25 nm range generally anticipated for 7 nm node EUV masks. This very well could be due to the design type and design MEEF. This further accentuates the need for actinic 'litho-based' inspection capability.

Figure 14 provides a comparison between SEM defect size, EUV AIMS™ printability and the signal strength at inspection for defects that fail the 10% printability target, and those that do not. All of these defects were detected during the high-sensitivity inspection. Signal strength is defined as the defect 'residual' seen at inspection.

6. Summary

Defect Sensitivity versus Wafer Printability

This study has demonstrated that a 19x nm inspection system is capable of detecting EUV mask defects that fail a 10% CD error specification on wafer, and in some cases, is able to detect defects that cause far smaller than 10% CD error on wafer. Keep in mind, that this evaluation only addresses absorber defects visible to a 19x nm optical mask inspection system and does not address multi-layer defects. The data in this evaluation represents defects detected at high sensitivity settings and uses multiple focus offsets and polarization conditions. The conditions presented here may not be applicable to high-volume manufacturing as it may require multiple inspection passes and significant optimization to improve inspectability. In addition, the wafer-printable linear defect size is smaller than anticipated for 7 nm EUV, and may be a factor of image size, image type and MEEF.

Defect Sensitivity Improvements

19x nm defect inspection is the strongest candidate for initial EUV production until high-throughput E-Beam or Actinic inspection is ready. In the meantime, this study has shown that the overall sensitivity of the 19x nm optical inspection systems can be improved for EUV mask inspection by optimizing combinations of focus offsets and polarization settings. New inspection recipes could be established to reflect this new sensitivity. Through multi-pass inspection, defect sensitivity as small as 15 nm for point defects and 7 nm for CD errors can be achieved on 7 nm EUV hole and line/space designs. Based on this approach, this could extend the useful life of 19x nm optical inspection tools through 7 nm EUV production, and 5 nm EUV development for the detection of *absorber* defects only. The 19x nm optical inspection system can be a valuable part of an inspection approach that also uses actinic blank inspection tools for *multiplayer* defect detection, and defect avoidance techniques to minimize the impact of absorber and multi-layer defects on printed images.

Throughput and Optimization

A major recommendation of this study is to use multiple focus offsets, combined with multiple polarizations in order to approach—and in some cases—achieve or even exceed wafer printable defect sensitivity on a 19x nm optical mask inspection tool. Two questions come to mind relative to this recommendation…first, is this cost effective, and second, how does this impact turnaround time? If you consider three focus offsets times two polarizations, this equals a worse-case scenario of six inspections. Assuming each inspection requires 2.5 hours of tool time for a full-field inspection area of approximately 100 mm x 130 nm, these six inspections will use approximately 15 hours of time. Now consider that *one* full-field inspection at current e-beam inspection run times would require *weeks* to complete, 15 hours of 19x nm optical inspection tool time is a cost-effective way to achieve printable, or near-printable defect sensitivity while turnaround time issues are being addressed on e-beam inspection tools.

Optimization can be achieved in several ways. One is to optimize inspection settings to minimize nuisance detections, while keeping in mind that this might result in desensing some features such as SRAFS, corners, notches and numbs in order to maintain high sensitivity on primary lines and spaces. A second way to optimize is to tailor the selection of focus-offset settings to match a given process capability. For example, if a process seldom produces clear defects, it may be possible to eliminate focus offset settings that optimize clear defect sensitivity and still achieve printable sensitivity on other defect types, but with fewer inspections.

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Industry Briefs

Intel Denies Media Reports Claiming it Cancelled its 10nm Process

Joel Hruska

Intel's 10nm process has been bedeviled by delays and problems — the node is years late already, and it may not debut at volume until Q4 2019. New media reports suggest that Intel has cancelled the node completely, while Intel itself denies that charge. Unfortunately, it's not possible to see the actual evidence for its argument. But the better question to ask is this: Regardless of whether Intel canceled its previous 10nm process, would Intel walk away from being a leading-edge foundry? And the answer there is an obvious "No." In this context, " canceling" 10nm could mean something more akin to "drawing up a new plan for future node progression." There's too much at stake as far as Intel's perceived manufacturing prowess.

If the rumor is right, we'll likely hear about it before long. Intel, having previously repeatedly committed to a 10nm ramp in Q4 2019 will have to publicly notify its partners and investors about any delay, just as it notified them about the previous ones. The more likely for Intel is to still push forward with a "10nm" node with different characteristics —relaxed than the company's incredibly ambitious hyperscaling project.

https://www.extremetech.com/computing/279306-intel-denies-media-reports-claiming-it-cancelled-its-10nm-process

EUV and Expanding the SSD Ecosystem

Tom Coughlin

Samsung made some significant announcements at its Samsung Tech Day this week. This included 7nm lithographic processes using Extreme Ultraviolet (EUV), 500+ layer NAND in the future, a second generation Z-NAND and HBM, a smart SSD with an FPGA on the board, KV SSDs and a future native ethernet NVMe SSD and more.

Samsung announced that it has completed all process technology development and has started wafer production of its revoluntionary process node, 7LPP, the 7-nanometer (nm) LPP (Low Power Plus) with extreme ultraviolet (EUV) lithography technology. According to the company, «The introduction of 7LPP is a clear demonstration of Samsung Foundry's technology roadmap evolution and provides customers with a definite path to 3nm.

https://www.forbes.com/sites/tomcoughlin/2018/10/19/euv-and-expanding-the-ssd-ecosystem/#2f5ffb041ffe

Advanced Technology Key to Strong Foundry Revenue Per Wafer

The average revenue generated from processed wafers among the four biggest pure-play foundries (TSMC, GlobalFoundries, UMC, and SMIC) is expected to be $1,138 in 2018, when expressed in 200mm-equivalent wafers, which is essentially flat from $1,136 in 2017, according to a new analysis by IC Insights. The average revenue per wafer among the Big 4 foundries peaked in 2014 at $1,149 and then slowly declined through last year, based on IC Insights' extensive part-two analysis of the integrated circuit foundry business in the *September Update to The 2018 McClean Report.*

Although the average revenue per wafer of the Big 4 foundries is forecast to be $1,138 this year, the amount generated is highly dependent upon the minimum feature size of the IC processing technology. In 2Q18, there was more than a 16x difference between the 0.5μ 200mm revenue per wafer ($370) and the ≤20nm 300mm revenue per wafer ($6,050). Even when using revenue per square inch, the difference is dramatic ($7.41 for the 0.5μ technology versus $53.86 for the ≤20nm technology). Since TSMC gets such a large percentage of its sales from ≤45nm production, its revenue per wafer is expected to increase by a compound annual growth rate (CAGR) of 2% from 2013 through 2018 as compared to a -2% CAGR for the total revenue per wafer average of GlobalFoundries, UMC, and SMIC during this same time period.

https://electroiq.com/2018/10/advanced-technology-key-to-strong-foundry-revenue-per-wafer/

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24-28 February 2019
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