Process resilient overlay target designs for advanced memory manufacture

Joonseuk Lee[b], Mirim Jung[b], Honggoo Lee[b], Youngsik Kim[b], Sangjun Han[b], Michael E. Adel[c], Tal Itzkovich[c], Vladimir Levinski[c], Victoria Naipak[c], Anna Golotsvan[c] , Amnon Manassen[c], Yuri Paskover[c], Tom Leviant[c], Efi Megged[c], Myungjun Lee[a], Mark D. Smith[a], Dohwa Lee[d], Dongsub Choi[d], Zephyr Liu[d]

[a] KLA-Tencor Corp, One technology Dr, Milpitas, CA, 95035, USA
[b] SK Hynix, 2091 Gyoungchung-daero, Bubal-eub, Icheon-si, Gyeonggi-do, Korea
[c] KLA-Tencor Israel, 1 Halavyan St. Migdal Ha'emek, 23100, Israel
[d] KLA-Tencor Korea, 53 Metrapolis-ro, Hwasung city, Gyeonggi-do, Korea

ABSTRACT

In recent years, lithographic printability of overlay metrology targets for memory applications has emerged as a significant issue. Lithographic illumination conditions such as extreme dipole, required to achieve the tightest possible pitches in DRAM pose a significant process window challenge to the metrology target design. Furthermore, the design is also required to track scanner aberration induced pattern placement errors of the device structure. Previous work[iii], has shown that the above requirements have driven a design optimization methodology which needs to be tailored for every lithographic and integration scheme, in particular self-aligned double and quadruple patterning methods. In this publication we will report on the results of a new target design technique and show some example target structures which, while achieving the requirements specified above, address a further critical design criterion – that of process resilience.

Keywords: Overlay metrology target design, OPC, Lithography, Pattern placement error (PPE), Depth of focus (DOF), SCOL, AIM, SADP

1. INTRODUCTION

Product shrinkage continues to drive the semiconductor industry roadmap in all segments. While semiconductor market segments might differ in some of the challenges they face, ever tightening overlay requirements remain common motif both for memory and logic production. Particularly, for DRAM segment, smaller devices drive On Product Overlay (OPO) specifications to bellow 3nm exerting significant difficulty both for lithography and overlay metrology (Figure 1 OPO trend).

Device shrinkage driven transition to extreme illumination conditions (e.g. extreme dipole or SMO), required for lithography resolution enhancement, often narrows the process window for overlay target to the point, where it does not any more overlap with operation conditions, optimized for device fabrication. Moreover, difference in typical dimensions between overlay targets, that should be resolvable for visible light metrology, and integrated circuits components (devices) lead to different responsivity of the two to virtually any process parameter, even down to the level of optical aberrations of the scanner[iii], which, in turn cause significant offsets between overlay measured at metrology target and actual OPO.

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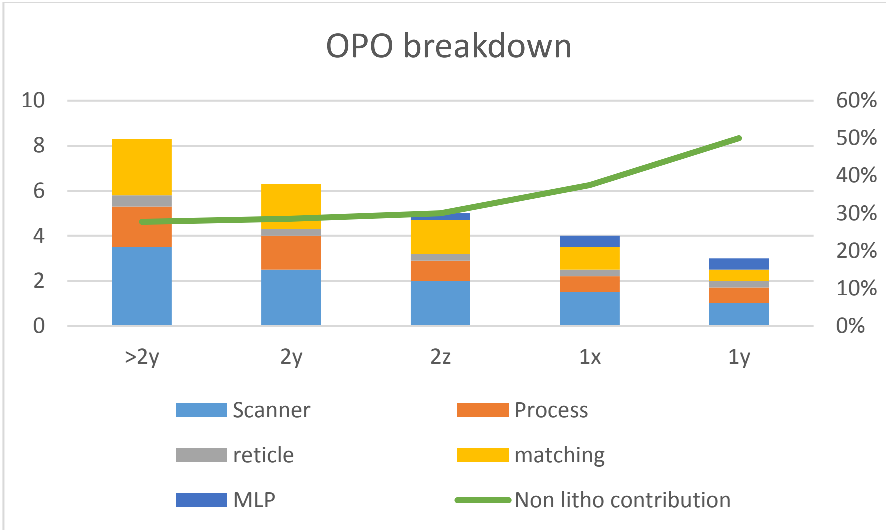


Figure 1: On product overlay trend showing the increase in non-lithographic contribution as scanner performance continues to improve

To overcome this mismatch, we introduce the ProAIM™ targets that intend to mimic device feature design, resulting in device like behavior upon excursions in process parameters. The metrology performance, that might have been compromised by the new target design is restored by Archer600 having new - polarized measurement mode, particularly suitable to ProAIM™ targets.

2. PROAIM TARGET DESIGN CONCEPT

At technology development phase, the semiconductor manufactures optimized their process (litho, etch, CMP, layers deposition, etc.) according to the device structures which are commonly dense pattern, as opposed to the OVL targets that are periodic structures of 'bar' (pattern area) and space (un-patterned area). For Imaging based target (AIM) the space size is about ~0.5µm (Figure 2). The periodic structures are required in order to detect pattern placement, generate signal (Kernel) and translate it to OVL values.
In order to reduce the un-patterned area, but still maintaining a periodic structure that can be resolved for pattern placement detection, new ProAIM™ target design was developed.

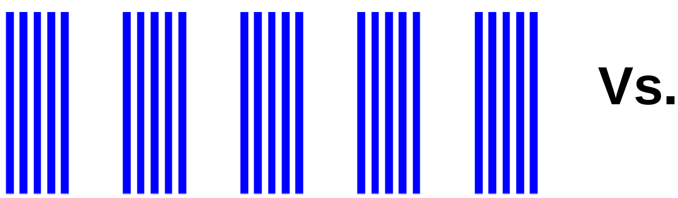


Figure 2: Conventional AIM target design.

2.1 ProAIM™ CDM & FFM

ProAIM™ CDM (Critical Dimension Modulation) and ProAIM™ FFM (Fill Factor Modulation) are periodic patterns where each period is constructed of lines with different CD (**Figure 2**). As the CD or pitch changes, the effective permittivity of a medium is changed, hence the optical properties of the layer changed, affecting the optical path of rays reflected from the target.
Since the segmentation (fine) CD and pitch are at the order of the device design rules, the target will demonstrate[iv]:

1. Good printability through the process focus process window.
2. Good PPE correlation to device.
3. Excellent process compatibility.

The ProAIM^{TM} FFM (Fill Factor Modulation) target type is an extended solution of ProAIM^{TM} CDM for SAxP patterned layers. The ProAIM^{TM} FFM target is built of periodic patterns where each period constructed of lines with different pitch (**Figure 3b**).
At SAxP patterning the final patterned CD on the wafer is fixed and depend on the spacer CD, therefore, CD modulation cannot be generated as final pattern. However, if CD modulation approach is applied at litho (mandrel) step, then after SAxP patterning flow is completed, the spacers pitch, which is defined by mandrel CD, is modulated (hence fill factor modulation), which can generate contrast as describe before. The ProAIM^{TM} FFM targets will have same litho Printability and PPE as ProAIM^{TM} CDM and process resilience as a dense structure.
Figure 3c show image of ProAIM^{TM} FFM measured by Archer600. The contrast of the periodic structure is sufficient to generate pattern placement signal.

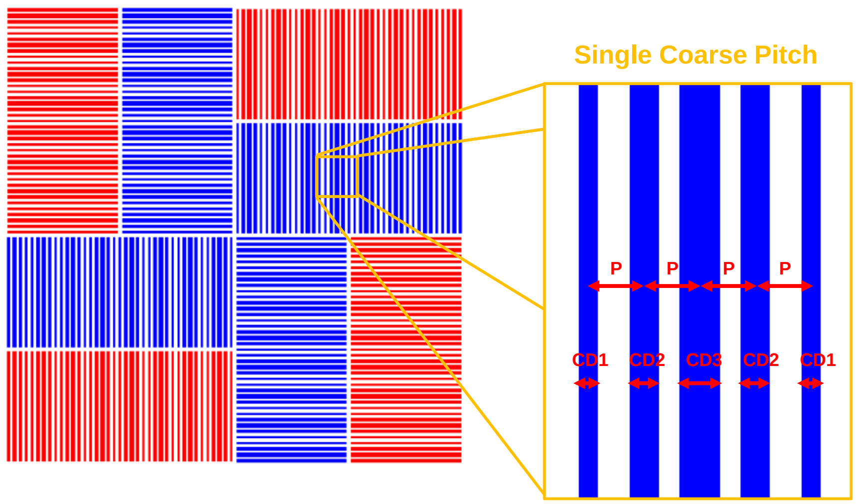


Figure 3: Design of ProAIM^{TM} CDM, where the repeated structure (coarse pitch) is built of lines with fixed CD and modulated CD.

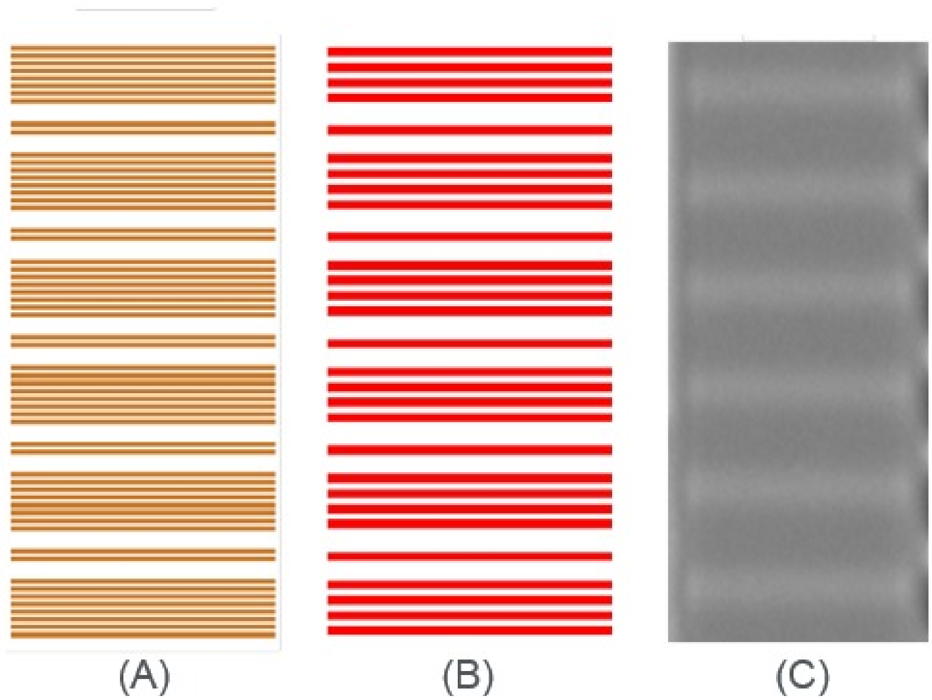


Figure 4: Design of ProAIM^{TM} FFM for SADP processed layer. (a) (upper image) is the design of FFM at mask (litho) level. (b) (middle image) is the final pattern on the wafer after SADP sequence is completed (spacer pattern). (c) (bottom image) is the resulted image by Archer600. The periodic structure has good contrast and can be used for OVL measurement.

2.2 ProAIM^{TM} FS

In ProAM FS (Fully Segmented) target concept, the space between the bars is filled with lines that are perpendicular to the lines in the bar (Figure 5). As described in figure 5, several parameters can be modified to optimize the target design such as the bar (original lines design), space (perpendicular lines) and the ration between them to find the most process compatible condition. The design rules of each one can be either the same or different to meet lithography printability conditions. The distance between horizontal and vertical lines (Δ) is defined by process (litho and other) to prevent issues such as bridging, under etch, etc.

Since the patterning of this target is not continuous, this target does not gain litho PPE device correlation advantage, but in terms of printability, for layers printed by 2D illumination source, the device design rules can be maintained for both X and Y OVL strictures.

The advantage of this design is that according to AcuRate^{TM} simulations, for low contrast stacks this target results in better contrast then ProAIM^{TM} CDM/FFM designs. This advantage is achieved due to higher sensitivity of polarized light to the segmentation orientation.

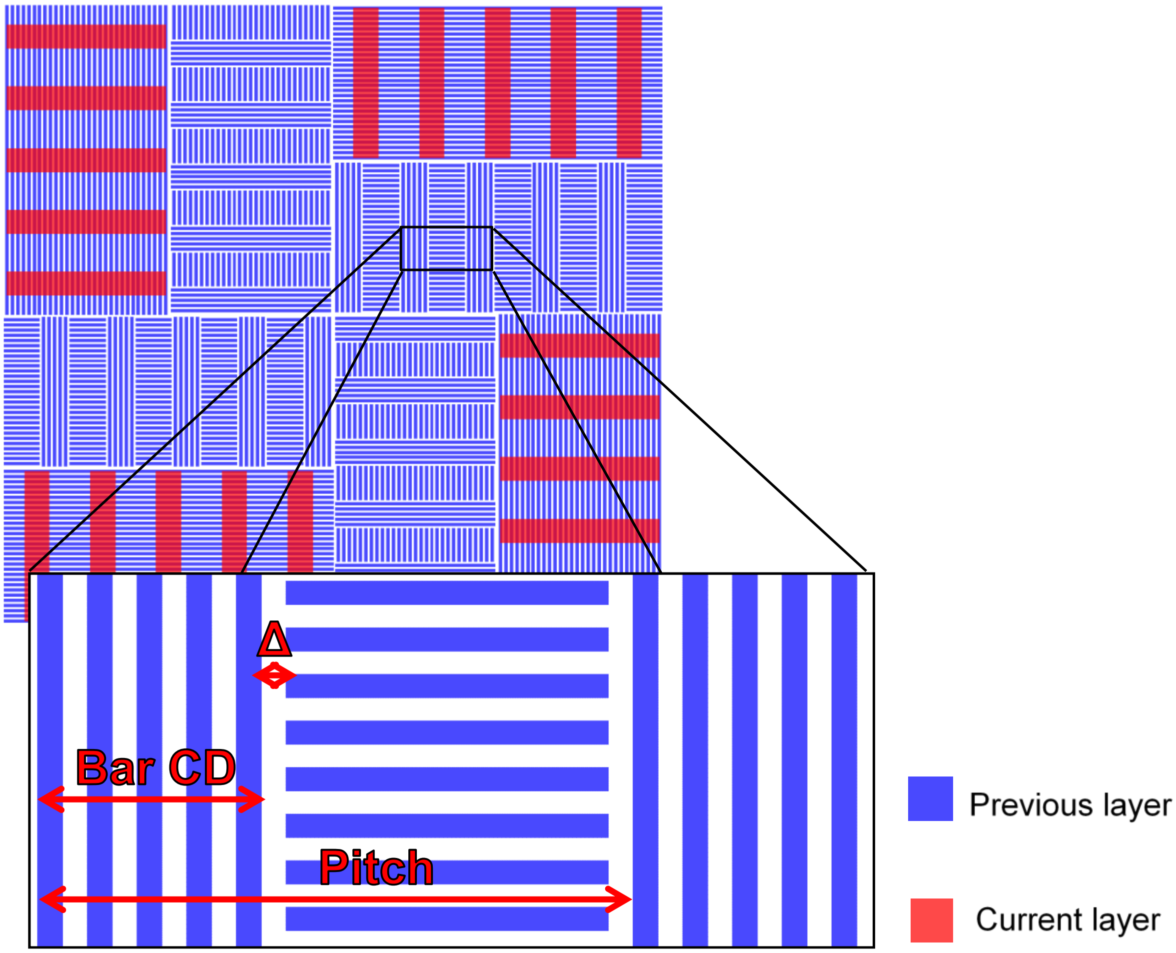


Figure 5: Fully segmented ProAIM™ target showing parameters that can be modified to optimize target design for specific layers.

In spite of all the benefit, these new designs do not come without a heavy price of contrast loss, as illustrated in **Figure 6**.

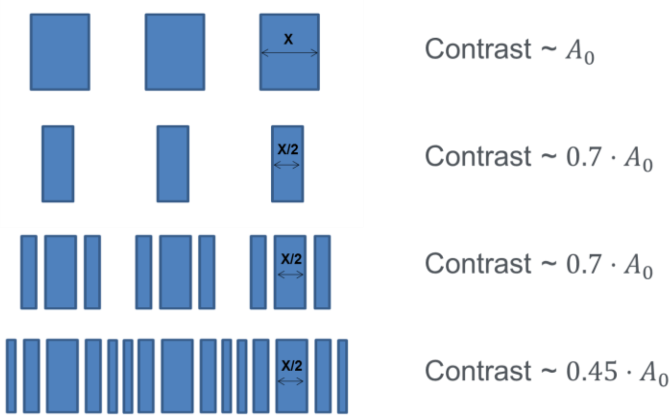


Figure 6: As the space between patterns is filled, the contrast is reduced up to ~45% of initial contrast.

There are two ways to enhance pattern contrast and overcome the contrast loss: one is by increasing the intensity of the signal (more energy), the other is by enhancing the contrast of the signal (higher gray scale differences). These two paths are enabled by the new advanced OVL tool Archer600™. For increasing signal intensity, the tool has increased light source brightness x8 compared to previous generation tool. For enhancing the contrast of the signal, using polarized light to measure ProAIM™ FS enhance contrast by the polarized light sensitivity to the different segmentation orientation. For ProAIM™ CDM/FFM the contribution of polarized light depends on the optical properties of the patterned materials and the interface layers.

3. THEORETICAL BACKGROUND

As depicted, ProAIM™ target design relies on heavy segmentation of bars and spaces, while alternating either segmentation direction, or segmentation density. In fact, the very nomenclature of "bars and spaces" is obsolete in relation to these targets, as regions within pitch now differ by their optical response, and not necessarily by total material composition.

The device-like segmentation pitches, are of scales much smaller than typical metrology wavelength, leading to significant birefringence of the target, as it falls into category described by effective medium theory. Figure 7 depicts two types of polarization interaction of electromagnetic field with subwavelength structures.

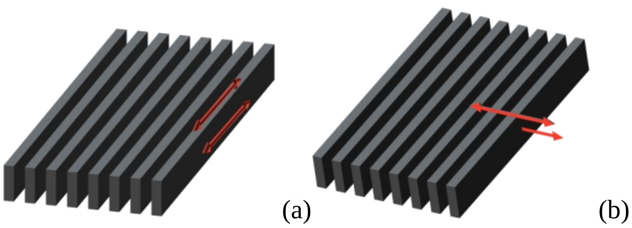


Figure 7: Transverse Electric (TE) – a. and Transverse Magnetic (TM) –b. waves interacting with subwavelength segments. Discontinuity of boundary conditions for TM wave at vertical walls of the segments exert different effective permittivity for the two waves.

Results of effective medium theory give rise to effective electric permittivity for each of the waves:

$$\epsilon_{TE} = \eta\epsilon_{Gr} + (1-\eta)\epsilon_{Sur}$$

$$\epsilon_{TM} = \frac{\epsilon_{Gr}\epsilon_{Sur}}{(1-\eta)\epsilon_{Gr} + \eta\epsilon_{Sur}}$$

Here η stands for the volume fraction of "grating" material in the target, ϵ_{Gr} is the relative permittivity of the grating material, and ϵ_{Sur} is relative permittivity of the layer being patterned.

This property is leveraged by Archer600 by enabling selection of polarization for optimization of metrology recipe. To exemplify the underlying benefit of polarized measurement we might take a look at simplified case of a target possessing segmentations only for "bars", and no segmentation for the "spaces" regions, as sketched at figure 8

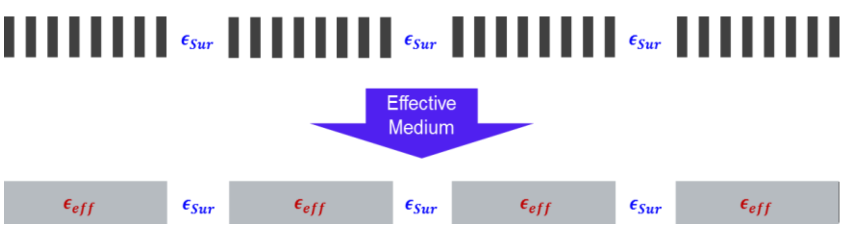


Figure 8: Effective medium approximation for segmented target. Effective medium predicts different optical response of such a target for TM vs TE polarizations.

From Born's approximation it follows, that diffraction efficiency, and thus image contrast of a grating is proportional to permittivity contrast between bar and space, which is in this case is $\epsilon_{eff} - \epsilon_{Sur}$. It is evident that if $\epsilon_{Gr} > \epsilon_{Sur}$, diffraction efficiency for TE wave will be greater than for TM one.

Despite the apparent simplicity of the effective medium, in real stacks, propagation effects, and particularly multiple reflections and refractions at every interface (as depicted in the figure 9) might obscure the simple diffraction effect. Nevertheless, measurement polarization selection introduces significant degree of freedom for recipe optimization.

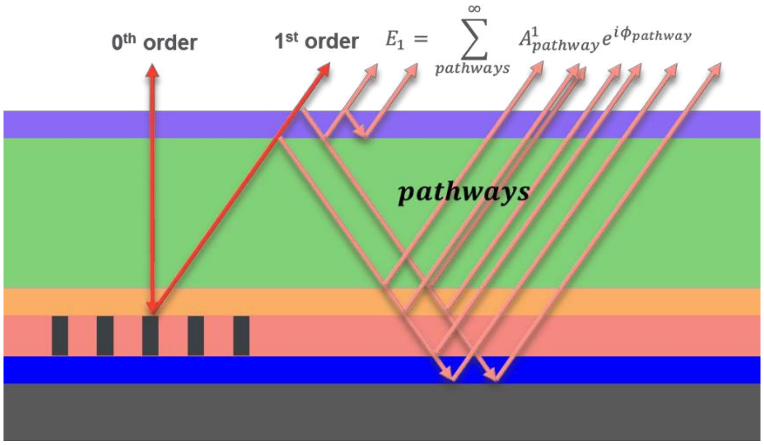


Figure 9: sketch of multiple pathways interfering at the top layer of the target. The final field measured at the detector is result of multi-beam interference.

4. EXPERIMENTAL DATA

In order to experimentally validate the effect of the polarized light on ProAIM™ targets, we tested two ProAIM™ targets vs. the AIM target at various DRAM layers.

Multiple target designs were simulated and tested using table 1 target DOE and performance was compared to the POR AIM targets.

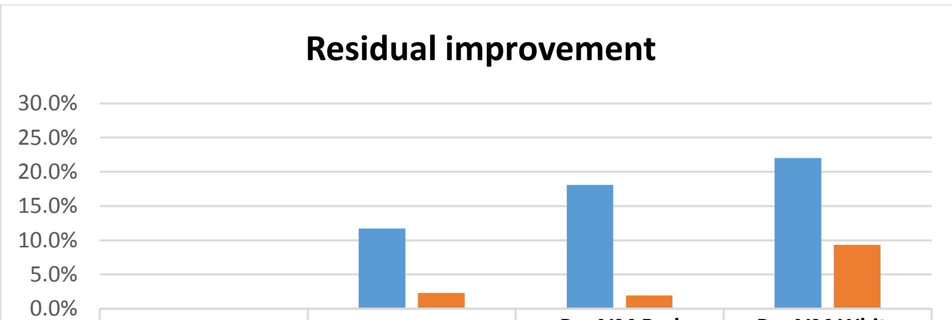
Pitch	Bar width	Previous Pitch	Previous Coarse CD	Target
Medium	Medium	Medium	Small	T1
		Medium	Small	
Small	Small	Medium	Medium	T2
		Medium	Medium	
Large	Medium	Large	Medium	T3
		Large	Large	
Medium	Medium	Small	Small	T4
		Small	Small	
Medium	Medium	Medium	Large	T5
		Medium	Small	
Large	Large	Large	Large	T6
		Large	Small	

Table 1: Target DOE table for one DRAM layer

The measurements were performed with the for full map sampling, 35 intra field locations with polarized and non-polarized light conditions on an Archer 600 tool - Quality metrics and residuals were collected.

4.1 ProAIM^{TM} improvement experimental data

ProAIM^{TM} targets were printed on a DRAM layer together with AIM targets. Both sets of targets were measured with an extensive cross wafer/field sample plan and results analyzed and modeled using high order correction model. In order to get the best results multiple measurement setups were tested using multiple measurement wavelengths and polarization states. Figure 10 shows the comparison best setups results for AIM and ProAIM^{TM} targets showing a significant residual reduction of over 10% when using ProAIM^{TM} targets.



	White Unpolarized	White Polarized	ProAIM Red Unpolarized	ProAIM White Polarized
X	0.0%	11.7%	18.1%	22.0%
Y	0.0%	2.3%	1.9%	9.3%

Figure 10. The residuals improvement with AIM and ProAIM^{TM} polarized vs. un-polarized illumination

To check the process resilience, we looked at the residual distribution across the wafer. Wafer to edge difference is a known process variation impacting overlay target quality and overlay target measurements. ProAIM^{TM} targets are closer to device design and expected to have reduced process variation impact compared to regular AIM targets. In figure 11 we can see the cross wafer residual data comparison between ProAIM^{TM} and AIM targets clearly indicating better edge performance of the ProAIM^{TM} targets.

(A)

(B)

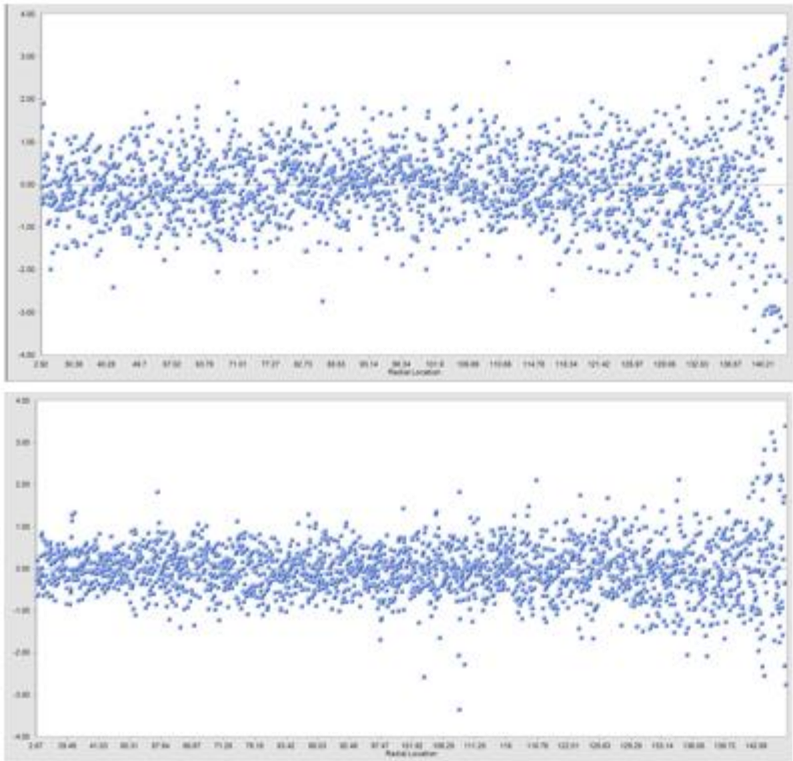


Figure 11 Residual data across wafer (a) AIM target residuals cross wafer (b) ProAIM^{TM} targets residuals cross wafer

It is worth noting that unlike the overall residuals improvement which is seen whenever ProAIM^{TM} targets are measured with Archer 600, the cross wafer improvement is seen only in part of the layers. This can be attributed to cross wafer process effects that impact the overlay including scanner registration and are not fully captured by the model or to further need for target design optimization. Figure 12 shows an example of residuals improvement which is seen at a different DRAM layer without changing the cross wafer signature.

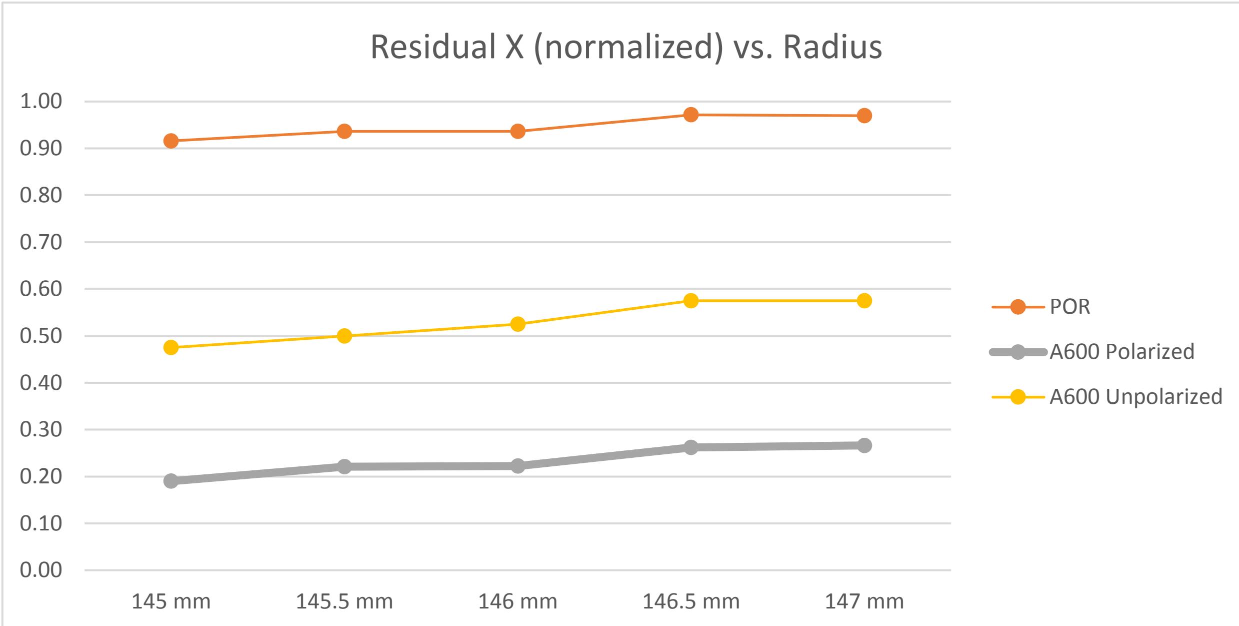
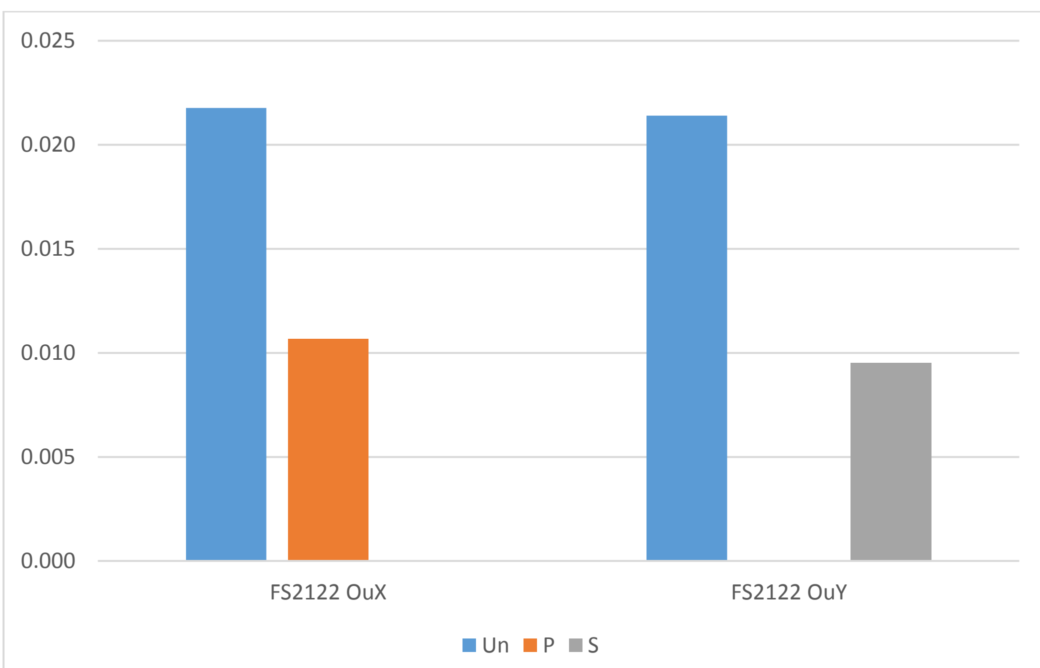


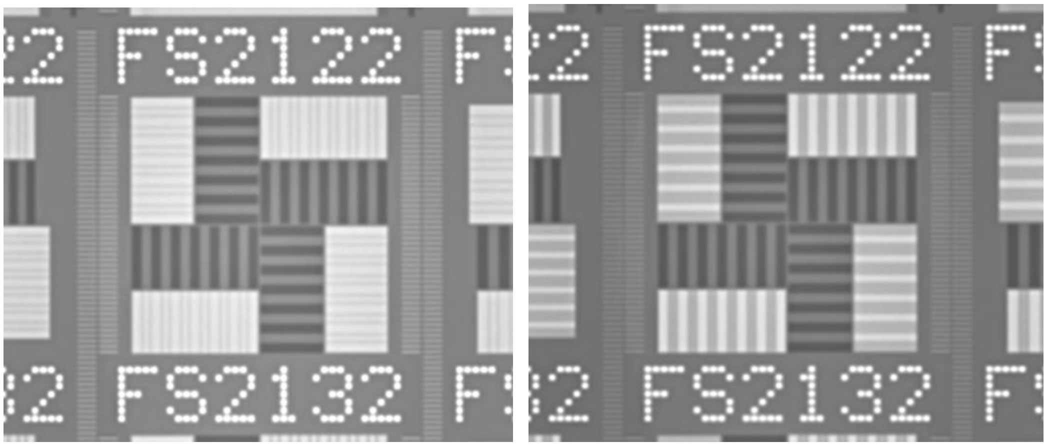
Figure 12. Normalized residual shows significant improvement with ProAIM^{TM} targets on Archer 600. Improvement is uniform across the wafer and does not show a center to edge signature.

4.2 Polarization improvement

Assessing polarization improvement was done on two different targets. First test was done on targets designed to maximize polarization impact. The targets have fine segmentation in both longitudinal and vertical directions and they were printed on a logic backend stack. As expected both polarization directions show a significant 50% contrast improvement (Figure 13a). The very large contrast improvement can be also seen when looking at the target pictures comparing the outside bar between the polarized and un-polarized illuminations (Figure 13b).



(a)



(b)

Figure 13. (a) Contrast precision measured on fully segmented targets with un-polarized and polarized illuminations. (b) Target pictures clearly showing the difference in contrast of outer bar between polarized and un-polarized illumination.

Second test was done with AIM targets on a few DRAM layers, measuring the targets with un-polarized light and with polarized light. Measurement was done using the same full wafer map to assess the impact on the residuals and polarized light improvement is seen in figure 11.

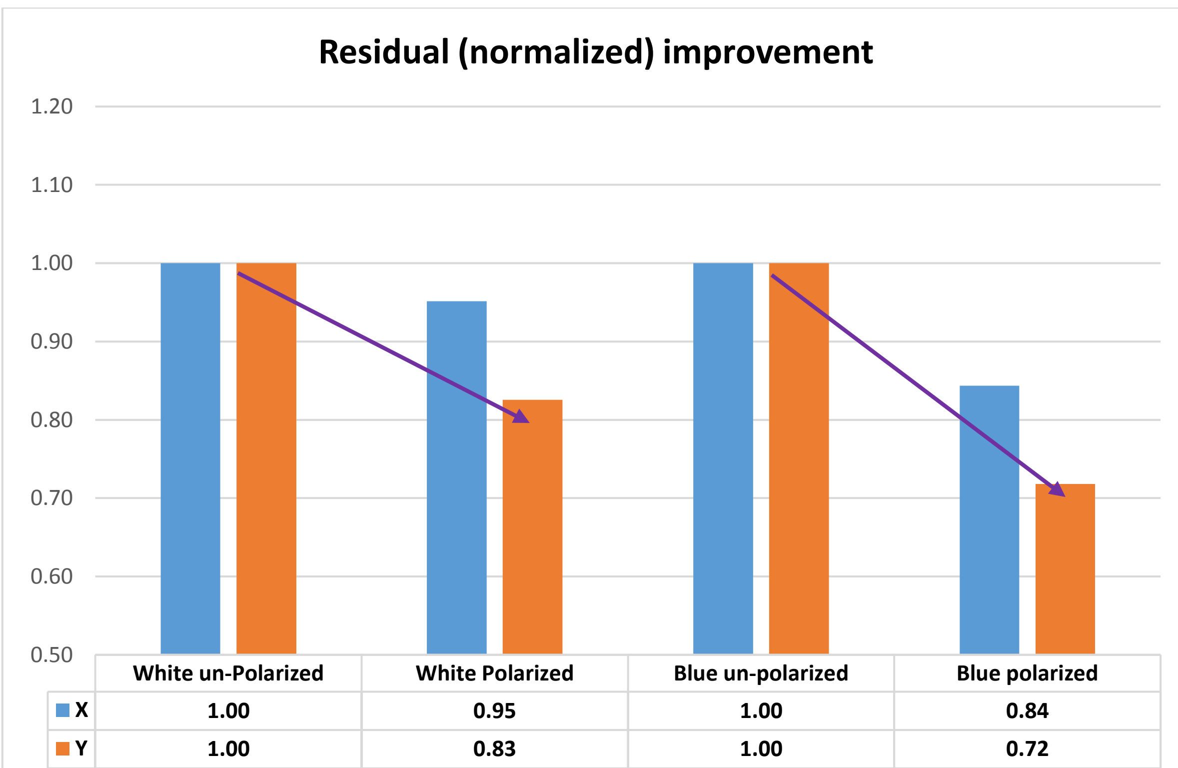


Figure 14. Residual comparison between polarized and un-polarized light with two setups.

5. CONCLUSIONS

In this paper we explored the impact of heavily segmented overlay targets measured with polarized light on contrast and residuals. We saw that this type of targets that mimic the device behavior are also more resilient to process variation and demonstrate improved residuals. We also saw that measuring these targets with polarized light enhances the contrast and enables accurate measurements. The combination of ProAIM™ segmented targets and overlay metrology tool with high intensity polarized light enables accurate measurements with good device correlation and improved process resilience. Moving to future technology nodes will continue to drive down OPO requirements, this in turn may require new target design with more flexibility and the ability to select a unique wave length for the specific layer measured.

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