MeRiT® repair verification using in-die phase metrology Phame®

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ABSTRACT

With the transition of lithography into 45nm node and beyond the industry faces the challenge that mask complexity increases steadily, mask specifications tighten and process control becomes extremely important. The use of Phase Shifting Masks (PSM), combined with off-axis illumination schemes, is essential to print feature sizes going beyond the lithographic wavelength. In conjunction with the shrinking feature size the tolerable defect size shrinks as well. This goes along with rising mask costs and therefore a high first pass yield becomes more important than ever. Repair strategies are required which have the potential to support the trend of decreasing tolerable defect sizes for both clear and opaque defects. In case of PSM it is not only important to remove material, of special interest is the capability to repair phase defects. This requires material deposition and etching accounting for transmission and phase as well.

The ebeam repair system MeRiT® MG 45 is based on the GEMINI® column and allows etching and deposition to repair both clear and opaque defects with high resolution and edge placement precision.

In this paper we focus on repair of phase defects on 6% att. PSM. We concentrate on 45nm lines/spaces looking into different defect dimensions. At feature sizes of 45nm CD, corresponding to 180nm CD at mask, feature topography already impacts the phase shift. Therefore a base line investigation is performed evaluating the correlation between deposited PSM layer height and phase shift covering also the impact of 3D mask effects on phase shift.

The deposited layer height is measured using AFM. For phase evaluation the newly developed phase metrology system Phame® was used. Phame® enables optical phase shift measurement with high spatial resolution down to 120nm half pitch on mask. On-axis and off-axis illumination can be applied according to the required scanner settings during wafer printing. Phame® captures imaging effects as well as 3D mask effects which are of special importance for further shrinking feature sizes.

Keywords: Phame, PSM, Phase metrology, Merit, Repair, ebeam repair

1. INTRODUCTION

The lithography world continues on its path of ever shrinking feature size and further extends 193nm lithography to 45nm node and beyond. This goes along with tighter specifications and increasing complexity of the masks and mask process control becomes extremely important. Phase shifting masks (PSM) stay the key solution to print feature sizes going beyond the lithographic wavelength. With the shrinking feature size the tolerable defect size shrinks as well and first pass yield is an important cost driver. Repair strategies are required which have the capability to support the trend of decreasing tolerable defect size for both clear and dark defects. The MeRiT® ebeam repair system has the capability to repair dark and clear defects as well. To evaluate defect printability and perform repair verification aerial imaging by AIMS™ is already well established in the mask shops.

In this paper we focus on repair of clear phase defects on a 6% attenuated PSM having 45nm lines/spaces (L/S). The most challenging part to repair a clear phase defect is to adjust phase and transmission correctly. The newly developed phase metrology system Phame® allows phase shift measurements in real production features down to 120nm half pitch on mask. The system was used to adjust the repair process in order to perform a perfect repair for phase defects in a 45nm pattern area. The methodology and results will be presented in this paper.

2. BASIC WORKING PRINCIPLE OF THE TOOLS

The phase metrology system Phame® is an optical system which allows actinic high resolution phase shift measurement down to 120nm half pitch on mask for all types of phase shifting masks. [1] On- and off-axis illumination including polarization can be applied using a mask side NA going up to 0.4 which is 1.6 NA scanner equivalent. This enables full compatibility to current and future 193nm immersion scanners down to the 32nm node. Due to the fact that Phame® measures under scanner relevant illumination settings the tool captures imaging effects as well as 3D mask effects which become especially important if the feature sizes shrink down to 45nm node.

Phame® uses a coherent 193nm illumination which is required for phase shift measurement. Therefore off-axis phase measurement is realized by applying consecutive measurements of single source points according to the scanner relevant illumination settings as to be seen Figure 1. The mask is handled face down and the phase image is captured in the wafer level plane with a Field of View (FoV) of 10µm x 10µm. Beside global phase evaluation considering the complete FoV phase evaluation can be done using either Region of Interest (ROI) evaluation or slice evaluation (see Figure 2). Please note, that this is a phase image and not an intensity image. As seen in Figure 3 both evaluation methods correlate very well and can be applied according to the customer needs.

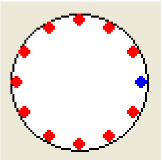

Figure 1: Schematic view of illumination sampling (here annular) at Phame®

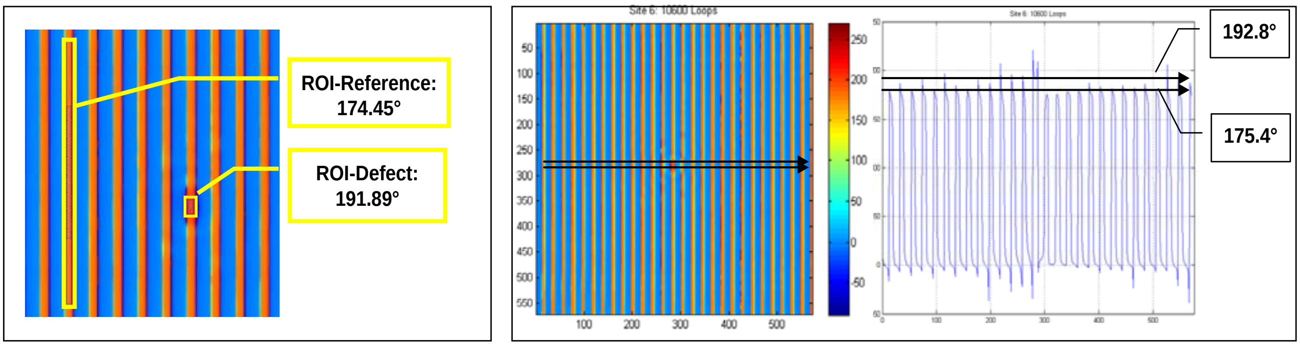

Figure 2: Phame®: In-die Phase Image showing phase shift evaluation using Region of Interest (ROI) (left) or slice evaluation (right)

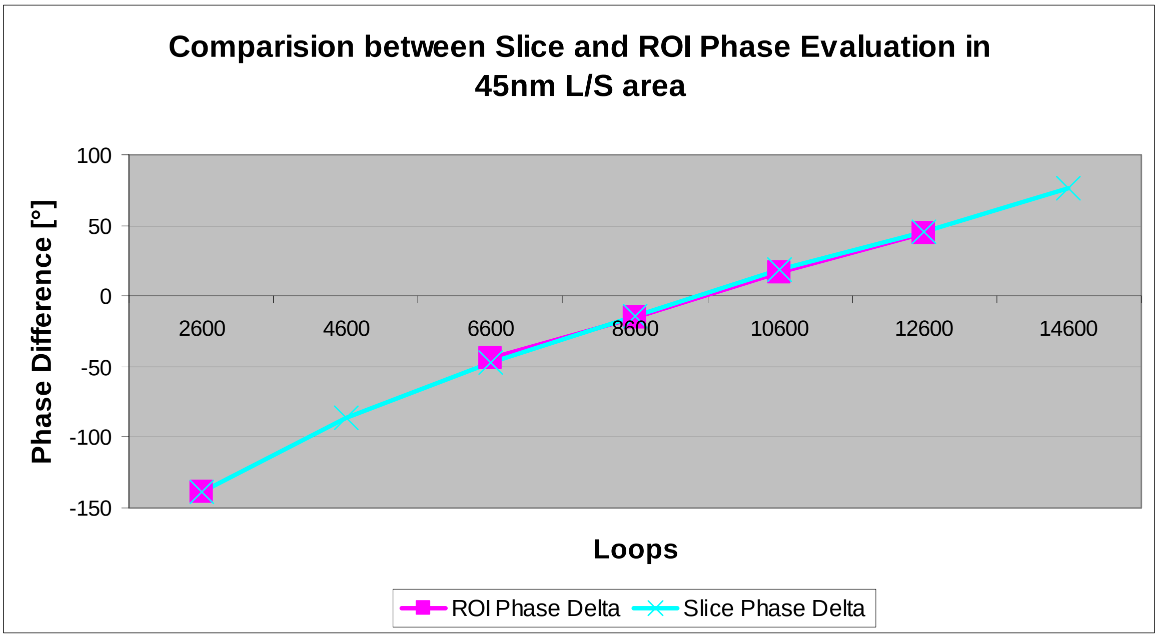

Figure 3: Comparison between Region of Interest (ROI) evaluation and slice evaluation

The ebeam repair system MeRiT® MG 45 is already well established in high end mask shops. It is based on the GEMINI® column which provides an ultra high resolution ebeam at low acceleration voltage. [2] The high precision gas injection system allows material etching and deposition to repair both clear and opaque defects with high resolution and edge placement accuracy. Figure 4 shows a schematic view of the ebeam etching and deposition process. Additionally the high quality electron optics provides a damage free inspection and imaging capability by using the system in SEM mode.

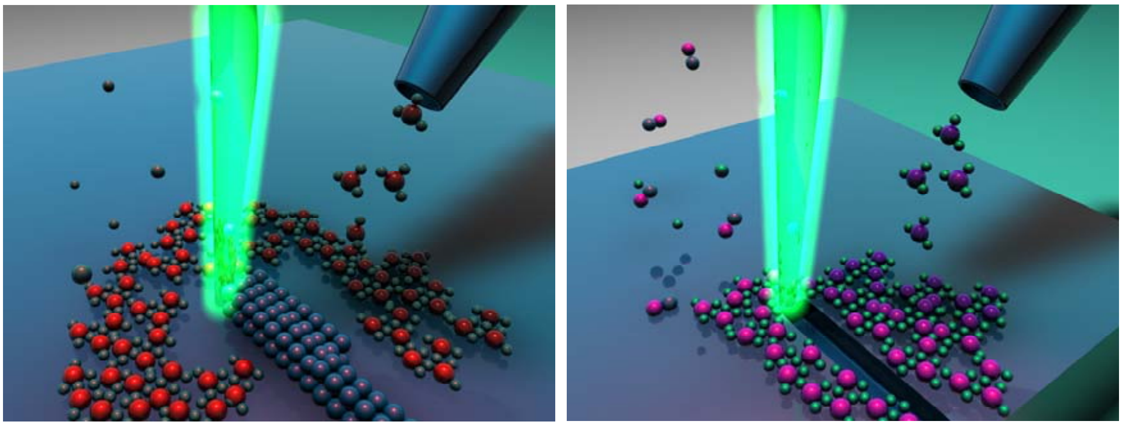

Figure 4: Schematic view on e-beam etch process (left) and deposition process (right)

One of the major benefits of the MeRiT® MG45 is the ability to repair clear defects on phase shifting masks. The proprietary method of matching the phase shift and absorption allows the MeRiT to repair clear defects that match the properties of various phase shifting masks. Figure 5 shows that especially for attenuated PSM phase and transmission need to be adjusted simultaneously.

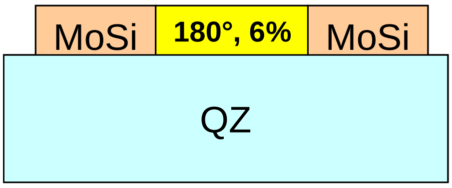

Figure 5: Repair scheme for phase defect, phase shift and transmission needs to be adjusted simultaneously

3. EXPERIMENTAL

A 6% attenuated PSM was used to investigate the complexity of a phase shift repair process. The mask contains a variety of different lines/space pattern having different programmed defect types and sizes. We focused on a broken line phase defect which is embedded in a 45nm lines/space pattern corresponding to 180nm lines/spaces on the mask. The investigated defect size is 180nm x 320nm at mask level as shown by the MeRiT SEM image in Figure 6. As expected the missing MoSi-line leads to a phase error which is impressively demonstrated in the phase image taken by Phame® (Figure 5).

The repair process was done using the MeRiT® MG45. The adjustment and fine tuning of the repair process was done in two steps:

- Adjustment of the pure phase shifting layer for phase correction
- Adjustment of absorption for transmission control

The phase measurements were performed on Phame® using a NA of 1.2, sigma 0.9, annular illumination (see Figure 1). The deposited layer height was measured with Atomic Force Microscope (AFM) in non-contact mode.

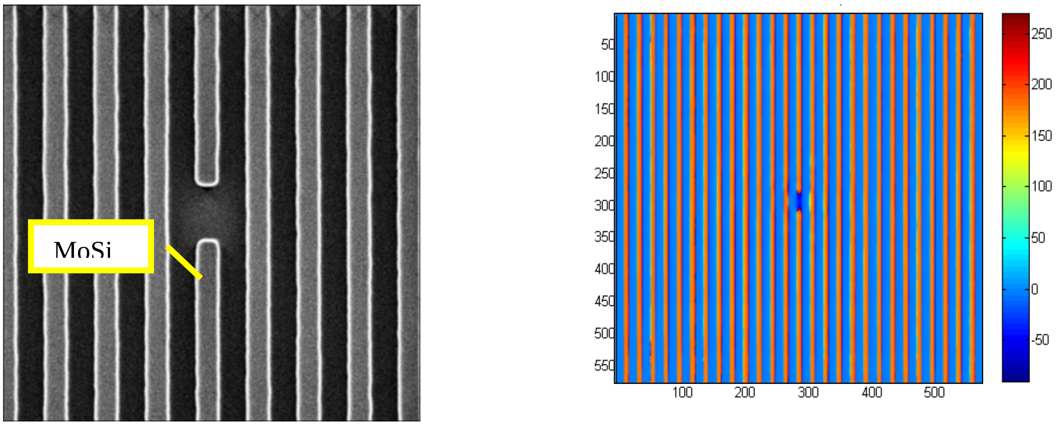

Figure 6: MeRiT® SEM Image of phase defect (broken line) on 6% att. PSM 45nm L/S (left) and Phame® phase image of phase defect (right)

4. RESULT DISCUSSION

As already pointed out the most critical part to repair a clear phase defect is that phase and transmission needs to be adjusted simultaneously. Therefore we started first with a basic investigation of the pure phase shift layer, evaluating the correlation between phase shift and deposited layer height over loops. Loops represent a process control parameter for the phase shift layer deposition. For this basic investigation phase shift layer cubes have been deposited having a size of 500nm x 500nm with varying height. As seen in Figure 7 phase shift and deposited layer height correlate very well for the pure phase shifting layer and show a linear behavior. For the 500nm x 500nm cubes a 180° phase shift would be achieved applying roughly 11000 loops for phase shift layer deposition.

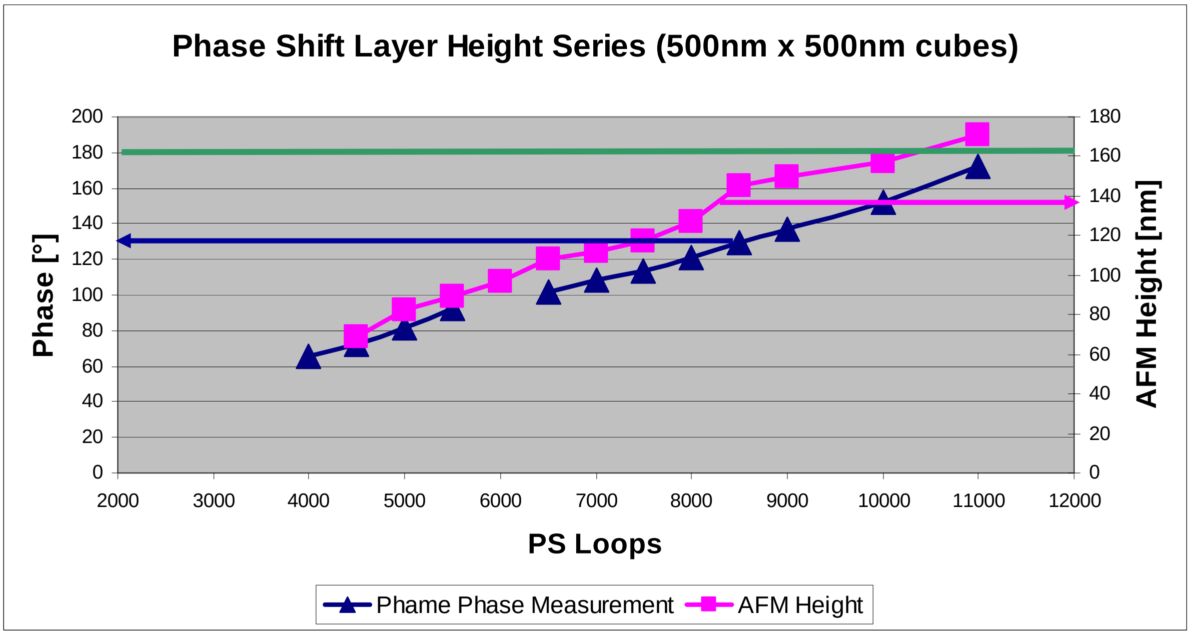

Figure 7: Comparison of phase shift and AFM layer height for base line layer deposition of pure phase shift layer using 500nm x 500nm cubes (Loops = process control parameter for deposition)

As already reported earlier [3] we know that 3D mask topography effects impact the phase shift significantly especially if the feature sizes go down to 45nm node. For that reason we investigated the phase shift behavior of the pure phase shift layer in the 45nm lines/space pattern of the 6% attenuated PSM using the broken line defect of 180nm x 320nm at mask level. This base line investigation allows the fine adjustment of the deposited phase shift layer according to the surrounding area. In Figure 8 the difference in phase shift between the reference area and the defect area is plotted. A perfect adjustment in phase to the surrounding area is achieved when the difference in phase shift is zero. Also in this case a linear correlation between phase shift and deposited layer height is observed. Perfect adjustment of the pure phase shift layer to 180° would be achieved using a process control parameter of about 9000 loops. Having this information the adjustment of the pure phase shift layer to 180° can be completed.

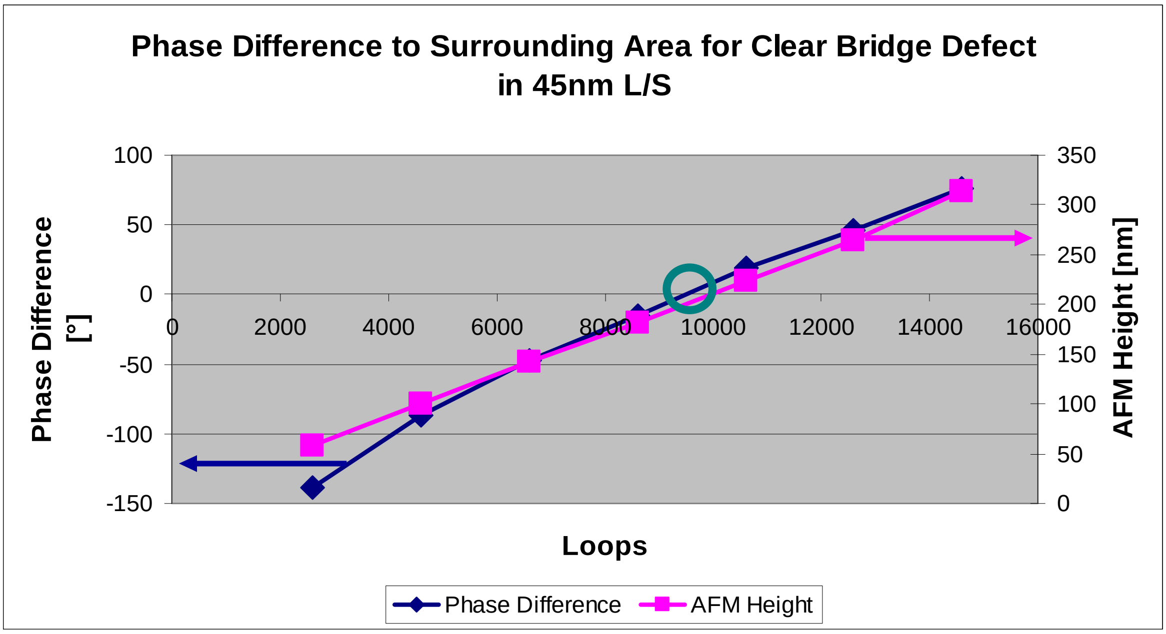

Figure 8: Fine adjustment of the pure phase shifting layer to the surrounding area on a 6% att. PSM with 45nm L/S, The green circle shows the optimum process parameter, where the phase difference to the surrounding is zero. (Loops = process control parameter for deposition)

To repair a clear phase defect the transmission needs to be adjusted as well. Therefore we investigated if the absorption control which is needed for transmission adjustment has an impact on the phase shift. Three different absorption levels have been deposited and the phase shift has been measured with Phame® and compared to the pure phase shift layer deposition as seen in Figure 9. As soon as the absorption is been considered in the repair process a significant impact on phase shift of about 10° is observed. A further variation of the absorption level represented by process A, B and C shows less impact on the phase shift. This result shows that the impact of absorption on phase shift needs to be taken into account to perfectly adjust the repair process. At the same time it illustrates the complexity of the phase shift repair process due to the non-linear behavior of the absorption control. With the in-die phase measurement capability of the Phame® the repair process can be exactly adjusted according to the phase shift requirements of the surrounding area of the phase defect.

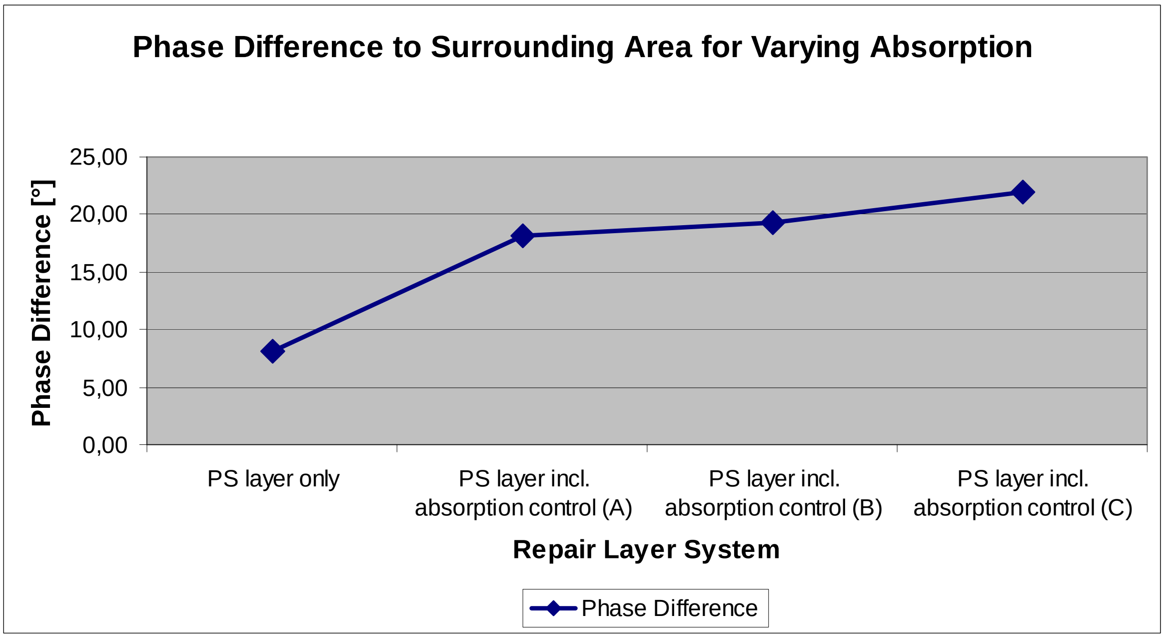

Figure 9: Investigation of impact of absorption on phase shift. Process A, B and C represents different absorption levels. There is a significant impact on phase shift by absorption. If the absorption level is varied the impact on phase shift is less. (PS = phase shift)

Furthermore we investigated the impact of different feature and defect sizes on phase shift. A reference process considering phase and absorption was exactly transferred from 180nm lines/spaces with defect size of 180nm x 320nm to 300nm lines/spaces with defect size of 300nm x 600nm. The Phame® phase shift measurements shown in Figure 10 demonstrate that 3D mask topography effects impact the phase shift as well which does not allow for a simple process transfer especially for small feature sizes.

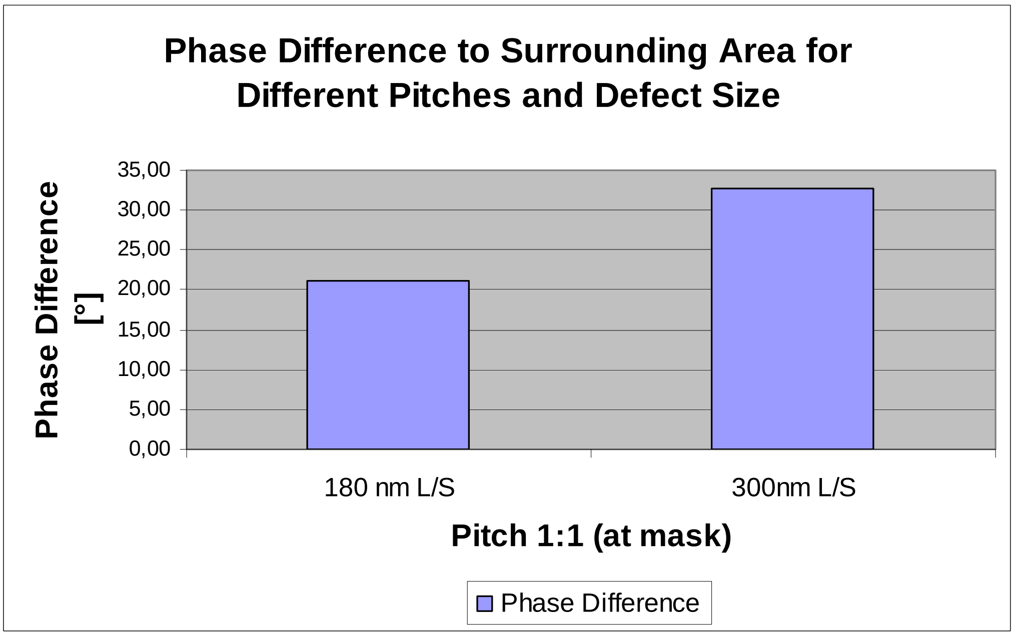

Figure 10: Process transfer from 180nm L/S (at mask) to 300nm L/S shows that there is an impact of feature size on phase shift, which does not allow a simple process transfer.

5. SUMMARY AND CONCLUSION

Phase shifting mask stay the key solution on the path of ever shrinking feature size. The repair of phase defects becomes an important process to fulfill the increasing requirements in terms of tolerable feature size. The ebeam repair system MeRiT® MG 45 allows repair of both clear and opaque defects with high resolution and edge placement accuracy. The presented work illustrates the complexity of the repair process of clear phase shift defects especially for attenuated phase shifting masks where phase and transmission needs to be adjusted simultaneously.

The phase metrology system Phame® measures the phase shift with high lateral resolution and enables the investigation of deposited layer height, absorption and feature respectively defect size on phase shift.

It was shown that the phase shift correlates very well with the AFM measured layer height for the pure phase shift layer. The in-die phase shift measurement showed that the phase shift also depends on the absorption which is required for transmission adjustment. Phame® allows the fine adjustment of the repair process according to refractive index, absorption and layer thickness. Furthermore it was shown that the phase shift depends also on feature and defect size due to 3D mask topography effects.

Phame® enables the industry to tune and fine adjust the repair process in order to realize a perfect repair of phase defects which will ensure a high first pass yield.

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