Phase metrology on 45-nm node phase-shift mask structures

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ABSTRACT

As PSM (Phase Shift Mask) process moves toward 45nm and 32nm node, phase control is becoming more important than ever. Both attenuated and alternating PSM need precise control of phase as a function of both pitch and target sizes. However conventional interferometer-based phase shift measurements are limited to large CD targets and requires custom designed target in order to function properly, which limits clear understanding and control of small target PSM features.

New type of Phase metrology tool created by Zeiss, in collaboration with Intel has been introduced and Intel's 45nm node PSM targets have been measured.

In this paper we present test results from AAPSM/EAPSM targets with space CDs down to 45nm a wafer-level. Smallest pitch was 300nm print pitch, 150nm CD at mask (75nm pitch at wafer). In addition to this, phase and transmission matching between conventional phase metrology tool and new tool has been investigated and shown.

Keywords: Phame, phase, phase metrology, scanner phase, off axis illumination, PSM

1. INTRODUCTION

As wafer CD generations have moved into 45nm (and soon into 32nm), efforts in metrology has been focused on 1) accurately measuring CD linearity and uniformity across the mask, and 2) accurately measuring phase variation (AA/EAPSM) and transmission (EAPSM). Due to special requirement for RET (resolution enhancement techniques) required on many critical layer masks, often features with less than 100nm half-pitch (mask level) has to be printed on masks. In other words, although current CD generation is 45nm, and conventional 4-to-1 reduction ratio would require 45x4=180nm, in reality, many of RET features on photomasks would require targets with far-smaller sizes.

CD control on photo masks are usually done through the following processes: Exposure dose/focus change, photoresist develop and etch. Maintaining correct CD linearity and uniformity across the mask is key requirement for photomasks. Specifically for PSM, effect of CD uniformity (for both AA/EAPSM) and etch depth (AAPSM) also becomes important. So far phase measurement has been limited to either 1) measuring etch depth using AFMs, which has limits due to prove diameter, or 2) measuring large-feature phase using interferometer-based metrology tools.

AFM methods provide accurate glass etch depth measurement for AAPSM targets, and thus enables indirect calculation of phase value, assuming that trench profile or optical property of films are constant. However recently there have been multiple examples in which CD and trench profiles do affect phase values, and this deviation/variation tends to be stronger for smaller CDs. [1] AFM has limit in directly measuring phase variations for small targets.

Another existing phase measurement method has relied on optical interference between two beams passed through reference and target features in order to measure relative phase differences. Despite of many improvements in minimum measurable features in interferometer-based methods, they have so far lagged behind the pace of CD reduction in photomasks. Intel is now routinely measuring 70nm half pitch on photomasks as a part of 45nm/32nm requirements, yet interferometer based method can go down to >100nm at wafer level at best so far. [2]

A new phase metrology tool, conceived by Zeiss and co-developed with Intel has been introduced and began preliminary measurements on Intel-produced 45nm plates. Main goals Intel hopes to achieve with this new tool are as follows:

1) Measuring <100nm (on mask) half pitch features for both EAPSM and AAPSM
2) Measuring various different pitch/CD targets without having to rely on specially designed phase targets.
3) Dynamic repeatability meeting or exceeding that of existing interferometer-based phase metrology solutions.
4) Ability to duplicate or mimic illuminations used by wafer steppers.

This paper reports this new tool's setup and capability simulation, especially phase measurement uncertainty (variability) testing results from AAPSM and EAPSM test plates. Target measured was both EA/AAPSM 300nm pitch (on mask) nested lines. Static (consecutive measurements without pause or loading/unloading of plate in-between) measurements results met or exceeded requirement. We expect after second round of update and testing, these numbers will show further improvement over current one.

2. PHAME® - SET-UP

The optical beam path (Figure 1) of the new metrology system allows actinic phase measurements of 193nm photomasks with a mask side NA up to 0.4, which is 1.6NA scanner equivalent at the wafer. This enables full compatibility to future 193nm immersion scanners down to the 32nm node.

The 193nm laser is combined with a low sigma illumination unit that generates a coherent illumination (i.e. single source point) of the mask. The mask is handled face down similar to the scanner. On-axis or off-axis illumination including polarization can be applied depending on the PSM type. Partial coherent illumination settings of a scanner can be sampled in consecutive measurements of adjustable intervals allowing phase control under scanner relevant illumination settings. [3] The CCD-camera is in the same position as the wafer in the actual scanner. A stack of intensity images is captured during measurement. For each image the phase is manipulated by pupil filter. Phase information is obtained using iterative software algorithms. In addition to in-die phase shift, the tool also measures in-die transmission.

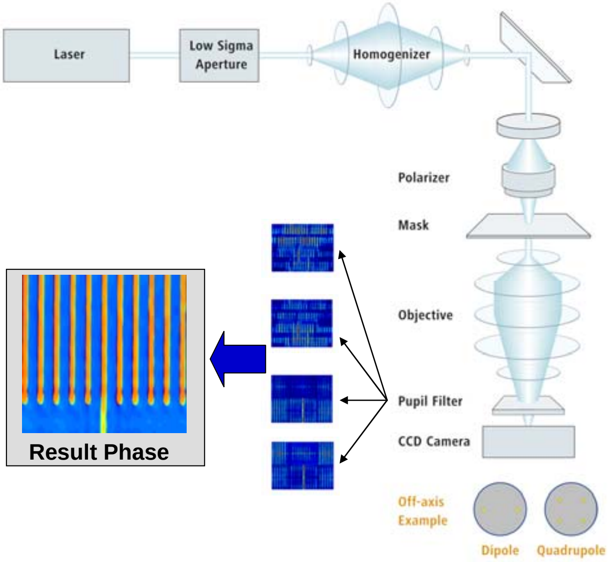


Figure 1: Optical beam path of Phase Metrology System – Phame®

The tool has full 45nm node and beyond production process capability. The operator GUI allows easy production use. Furthermore the tool has full automation capability including SECS/GEM and SMIF.

3. PHASE SHIFT VALUE ANALYSIS

Figure 2 shows a typical phase image measured with Phame®, in this case 45nm lines/space structures (at wafer) on MoSi PSM. Phase shift data analysis is done using histogram analysis. Once there are different pitches or features types in the field of view Region of Interests (ROI) can be defined. In this example a ROI has been defined for the dense lines and for the isolated line respectively as indicated in Figure 2.

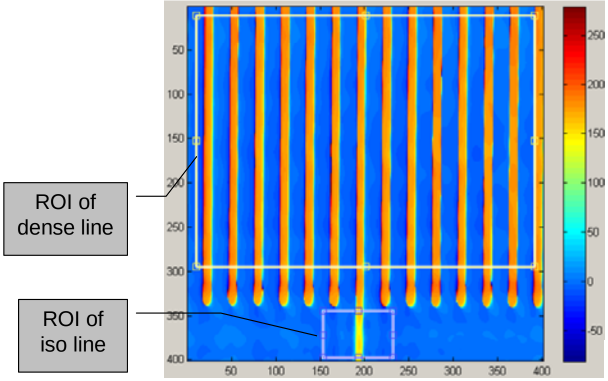
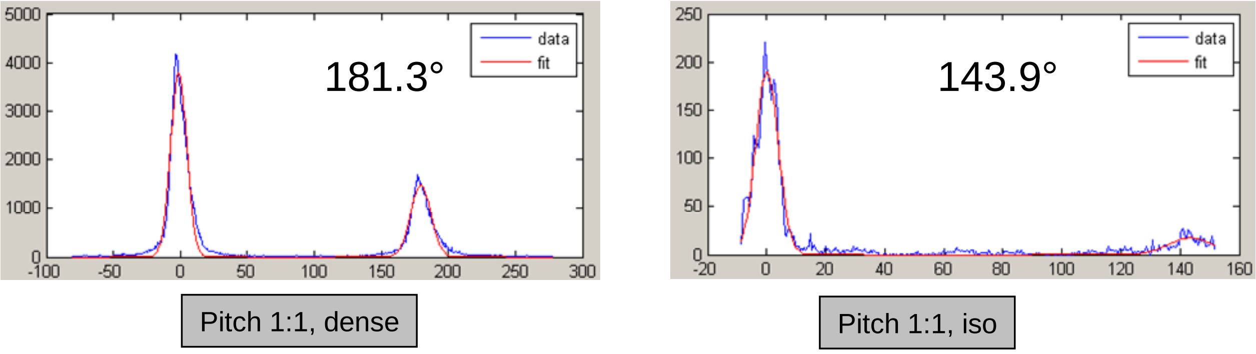


Figure 2: Definition of ROI (Region of Interest) for different pitches

For each ROI histogram analysis is applied. A Gaussian is fitted into the measurement data to account for statistical variations. The centre of gravity for each peak is algorithmically determined. The phase shift value equals the difference in-between these two points as shown in Figure 3.



Pitch 1:1, dense

Pitch 1:1, iso

Figure 3: Histogram analysis for dense and iso line for 45nm feature pitch 1:1 at wafer

4. MEASUREMENT RESULTS

For tool evaluation AAPSM and EAPSM test masks have been measured. The test masks contain large feature targets as well as small lines and spaces. The measurements and the result evaluation using global phase analysis have been done in automated mode.

In a first step static reproducibility has been analysed on large target features having a pitch of 4µm with 2µm CD at mask to get alignment to conventional phase metrology tools. Totally 30 measurement points have been taken for evaluation.

Figure 4 shows the static reproducibility for large features on AAPSM. The measurement results provided a mean value of 184.4° and a 3sigma value of 0.1°, which is very satisfying.

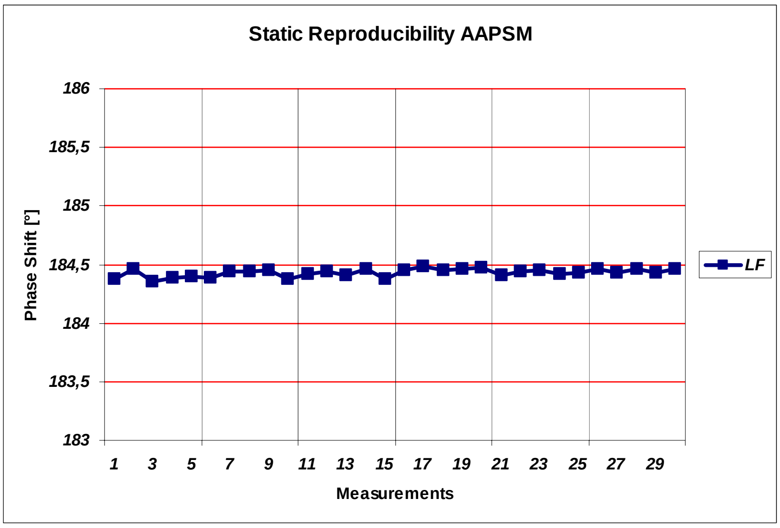


Figure 4: Static phase reproducibility on large features (LF), 2µm CD, 4µm pitch (mask level) on AAPSM

Figure 5 shows that for EA PSM the mean value is 178.1° with a 3sigma value of 0.2° for phase and 6.98% with a 3sigma value of 0.1% for transmission, also measured on large features. Compared to conventional phase metrology tools this is very well in line.

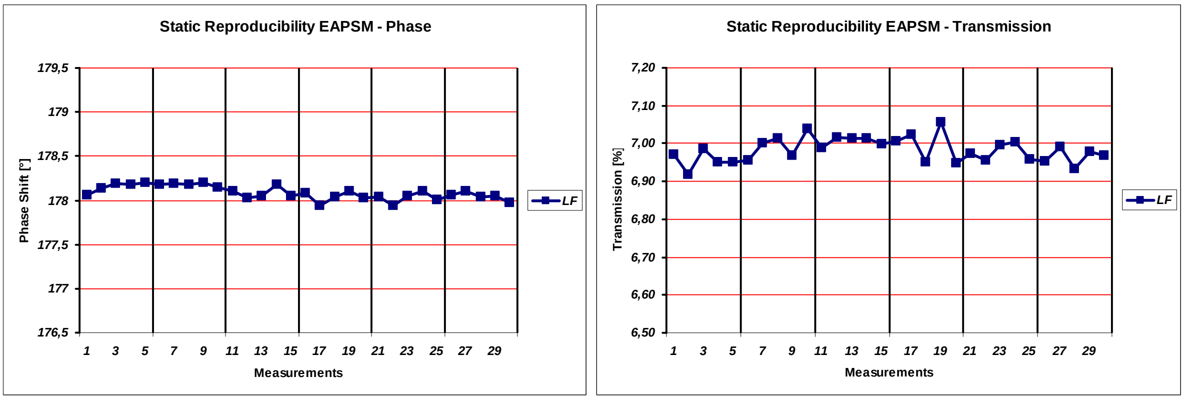


Figure 5: Static reproducibility for phase (left) and transmission (right) on large features (LF), 2µm CD, 4µm pitch (mask level) on EAPSM

In a second step the small feature capability has been investigated using an AAPSM. For static reproducibility measurement 30measurents have been taken using 1:1 lines/space features having a print pitch of 300nm with 150nm CD at mask level. The measurements show a phase shift mean value of 155.6° with a 3sigma value of 0.6° (see Figure 6). The small feature reproducibility is satisfying our current requirements.

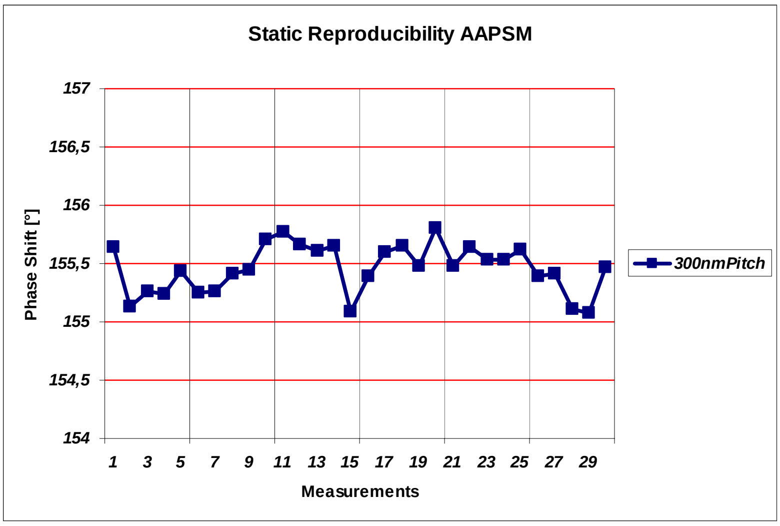


Figure 6: Static phase reproducibility on 1:1 lines/spaces, 300nm print pitch (mask level) on AAPSM

Furthermore first dynamic reproducibility measurements have been taken using an AAPSM test mask containing small lines/space features. For evaluation 1:1 lines/space features with 300nm pitch and 150nm CD at mask level have been chosen. Three different sites were measured which is called loop. The loops were repeated 3 times. After that the mask was unloaded and reloaded including alignment. The measurement was started again. This is called load here. Totally we performed 3 loads with each load containing 3 loops. The specification for short term dynamic phase reproducibility on small features is ± 1.2° 3sigma. Due to the limited number of measurement points we used range/2 values instead of 3sigma for assessment of short term dynamic reproducibility. The loop to loop reproducibility ranges from 0.07° to 0.41° range/2. The load to load reproducibility ranges from 0.27° to 0.52° per site. The detailed numbers are shown in Table 1. Further investigations on dynamic phase reproducibility will be done based on a higher number of measurement points.

Phase shift - short term dynamic - L/S: 300nm pitch, 150nm CD @ mask			
	L/S		
	Site 1	**Site 2**	**Site 3**
Load1 Loop1	160.38	162.02	162.34
Load1 Loop2	160.81	162.00	163.05
Load1 Loop3	160.54	162.14	162.48
Loop to Loop Range/2 Load1	**0.21**	**0.07**	**0.35**
Load2 Loop1	159.97	161.94	162.21
Load2 Loop2	160.43	161.19	162.98
Load2 Loop3	159.87	161.24	163.04
Loop to Loop Range/2 Load2	**0.28**	**0.37**	**0.41**
Load3 Loop1	161.19	161.92	162.95
Load3 Loop2	161.48	161.42	163.45
Load3 Loop3	160.72	161.82	163.11
Loop to Loop Range/2 Load3	**0.38**	**0.25**	**0.25**
Load to Load Range/2	**0.52**	**0.30**	**0.27**

Table 1: Short term dynamic reproducibility on 1:1 lines/spaces, 600nm pitch (mask level) over 3 Loads and 3Loops on AAPSM

Overall the first reproducibility values show a good tool performance. We expect further improvements in reproducibility by the continuous improvement program which Zeiss is currently executing on the Phame® System.

5. SUMMARY

The transition to 45nm and 32nm node requires accurate measuring of CD linearity across the plate as well as accurate measuring of phase and transmission variations on AAPSM/EAPSM. Especially for small target features diffraction limitations and 3D mask effects play an important role and needs to be considered. The new phase metrology tool Phame® of Carl Zeiss SMS allows laterally resolved phase measurement in any production feature of the active mask area for AAPSM and EAPSM.

The paper reported new type of PSM phase measurement system, and its measurement data from Intel's AAPSM/EAPSM test masks. Phase measurement static repeatability was tested with both large, conventional size features and small pitch targets with 300nm mask pitch. Both targets were successfully measured and static repeatability of phases met or exceeded that of existing phase metrology methods. For AAPSM test plates, short-term dynamic testing was also performed on small 300nm pitch targets and showed total load-to load range of 0.5~1°. The current results are based on a limited number of data points and have therefore preliminary character. We expect further improvement in a second round of update and measurements.

6. REFERENCES

[1] Toshio Konishi and Yosuke Kojima, "Through-pitch and through-focus characterization of AAPSM for ArF immersion lithography," *Proc. SPIE,* vol. 6281.62810S (2006)

[2] Sascha Perlitz, Ute Buttgereit, Thomas Scherübl, Dirk Seidel, Kyung m Lee, Malahat Tavassoli "Novel solution for in-die phase control under scanner equivalent optical settings for 45nm node and below" *Proc. SPIE,* vol.6607.66070Z (2007)

[3] Sascha Perlitz, Ute Buttgereit, Thomas Scherübl, Dirk Seidel, Kyung m Lee, Malahat Tavassoli "Novel solution for in-die phase control under scanner equivalent optical settings for 45nm node and below" *Proc. SPIE,* vol.6607.66070Z (2007)