Recent Performance Data of Sub-micron Features on Binary and Phase Shift Masks Utilizing the Leica Microsystems Inc. LWM 270 DUV Critical Dimension Metrology System.

John Whittey – Leica Microsystems Inc. 10761 Dixon Road, Oakdale, CA 95361 USA
E-mail: John.Whittey@Leica-Microsystems.com
Walter Steinberg – Leica Microsystems Wetzlar GmbH, P.O. Box 2040, D-35530 Wetzlar, Germany

Abstract

As the technology road map progresses and as the design criteria for each generation node shrinks, demand for smaller feature sizes continues to become more prevalent on photomasks. This demand combined with the Mask Error Enhancement Factor (MEEF) due to the various wafer stepper illumination techniques means tighter metrology precision tolerances for the measurement systems. Optical critical dimension (CD) tools are reaching the end of their current resolution limits without further improvements. Performance can be enhanced in ways other than just resolution increases. Measurement algorithms as well as illumination and magnification can be improved and increased to yield better performance, especially on certain feature types. Contacts and small features on a variety of mask types continue to challenge system capabilities. This paper demonstrates measurement results on different substrate and feature types using various improvements.

I. Introduction

A series of measurements have been performed on Leica's LWM 270 DUV system on both binary and Phase Shift Mask (PSM) types. Both short term and long term data are presented on different feature types. Measurements are done at the 248 nm illumination wavelength over periods from a few hours to 10 days. The LWM systems and the optics from Leica Microsystems have been described in detail in a number of prior papers [1,2,3,4,5,6].

Significant improvements have been made in light illumination homogeneity on the latest generation LWM DUV metrology systems. A micro-lens array has been added to the optics that has resulted in improved screen linearity, improved X/Y CD bias, and more reliable source illumination adjustments. Figure 1 shows the results of the pixel illumination with and without the micro-lens array in the optics. Figure 1 shows the intensity distribution in the pupil plane of the DUV Objective lens, with and without the micro-lens array.

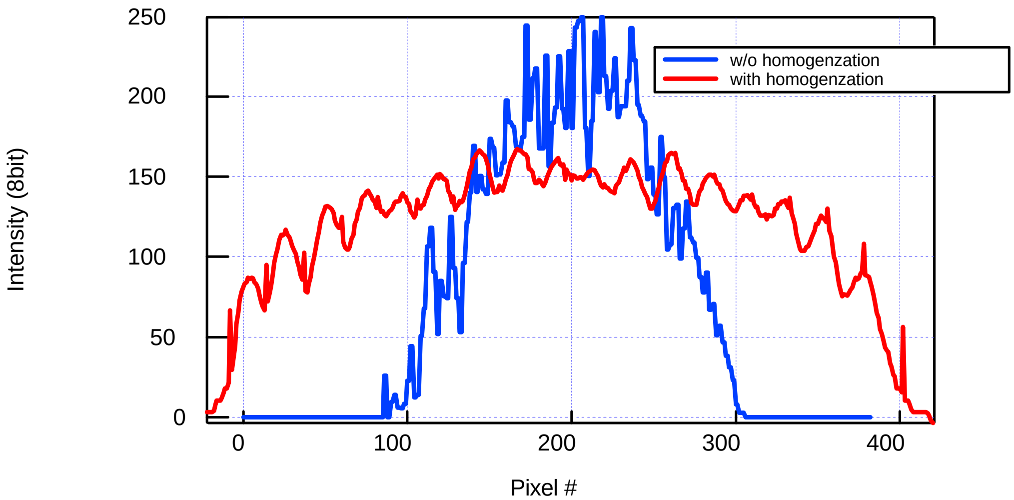

Figure 1

New through focus, line edge roughness and corner rounding algorithms have been added and improved. In addition to these algorithm improvements new pixel correction software and shading algorithms have been implemented to further improve light homogeneity and system performance. The measurement results being presented utilize many of these new improvements.

II. Short Term Repeatability Performance Binary Mask (Static and Dynamic)

The LWM 270 DUV measurement system is equipped with a 150x 0,90 NA DUV objective lens. The measurement system was used in a basic pitch calibration mode. The effective pixel size used during the measurement process is 16nm.

An improved “Through Focus” measurement algorithm was used for the measurements. This algorithm basically gathers a series of images at different focus planes in the “Z: axis and then analyzes the slope profiles to obtain the steepest areas. Once the optimum focal plane is determined then the profiles are analyzed for critical dimension size. Figure 2 shows short-term repeatability (static repeatability, 10 measurements) on a series of various size contacts on a binary mask.

The smallest contact measured was 0.25 micron. It is clearly apparent in this instance that repeatability is a function of feature size. Apart from the smallest features the repeatability is for features >= 0.4 micron is better than 2 nm. Also, the average 3 sigma of all measured contacts was calculated and is shown in Table 1.

Clear iso contact X	1.297 nm
Clear iso contact Y	1.66 nm

Table 1

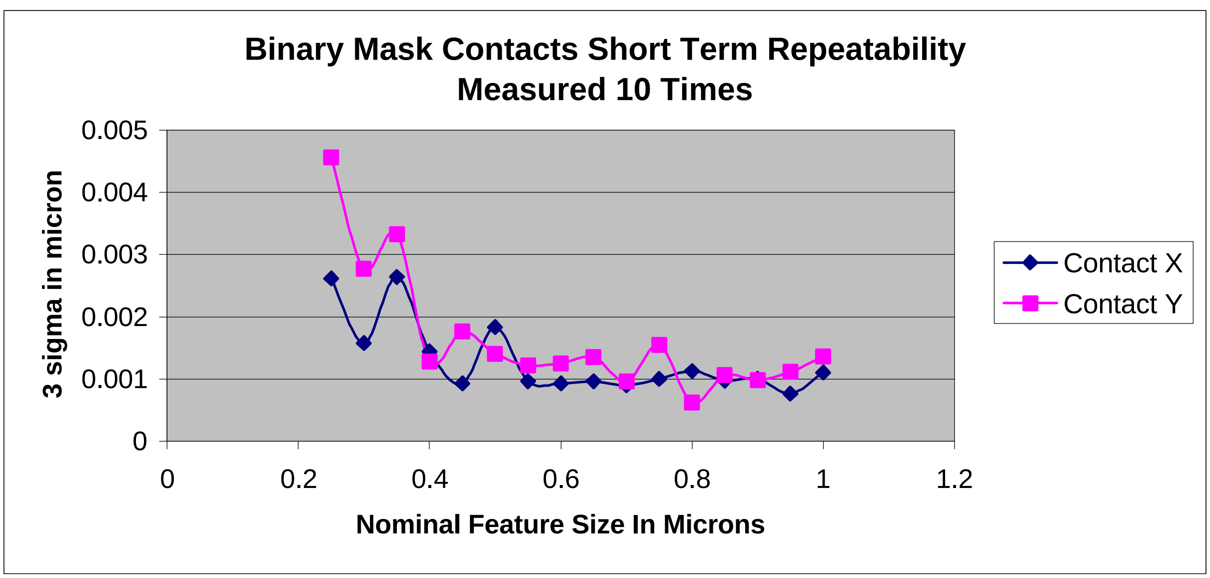

Figure 2

For dynamic repeatability a set of features ranging in size from 0,2 to 1 micron nominal size was measured 10 consecutive times. For each feature a complete loop of moving the stage, aligning the feature, performing a measurement, and then moving the stage to the next feature was performed. In this paper it is called dynamic repeatability. Isolated and dense lines, in dark and clear tones were measured. The measurements were taken by scanning through best focus.

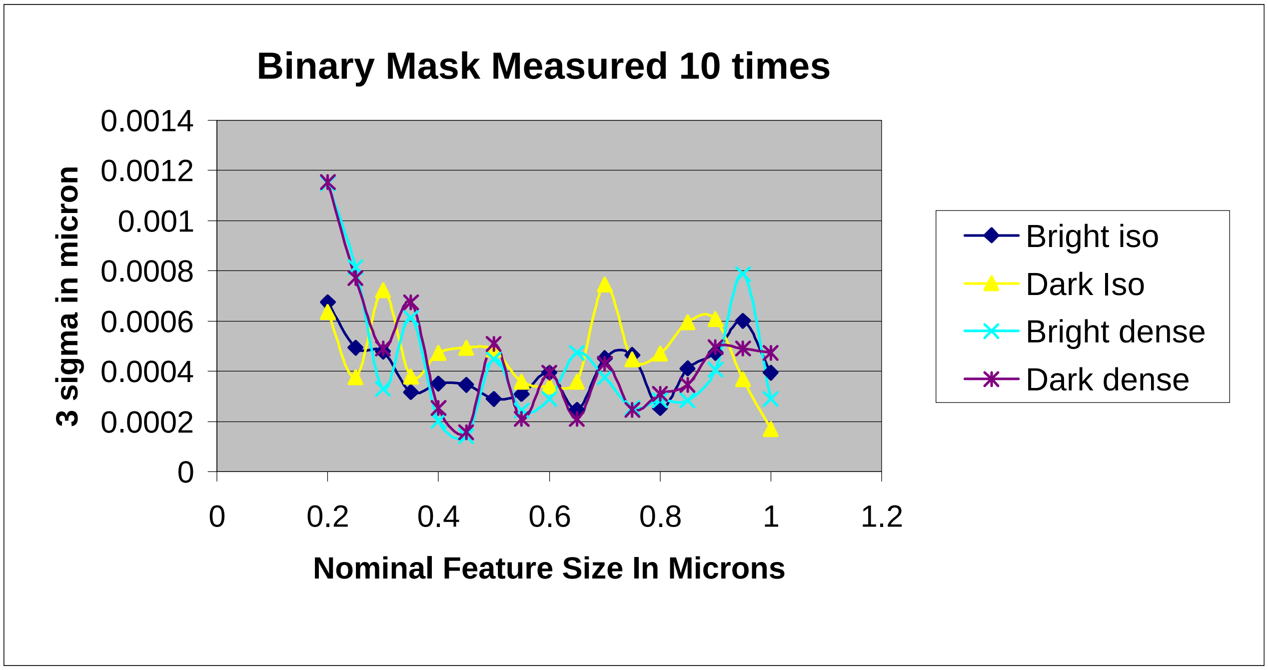

Figure 3

For features larger than 0.25 microns short term repeatability was better than 0.82 nm 3 sigma. To get an overview of the average performance on Lines and Spaces, the average 3-sigma value for each feature type is shown in table 2.

Dark iso Line	0.472nm
Dark dense Line	0.448nm
Clear iso Space	0.409nm
Clear dense Space	0.434nm

Table 2

III. Long Term Repeatability Performance Binary Mask (7 Days)

Figure 4 shows long-term dynamic repeatability over a period of seven days on both isolated and dense lines, clear and dark.

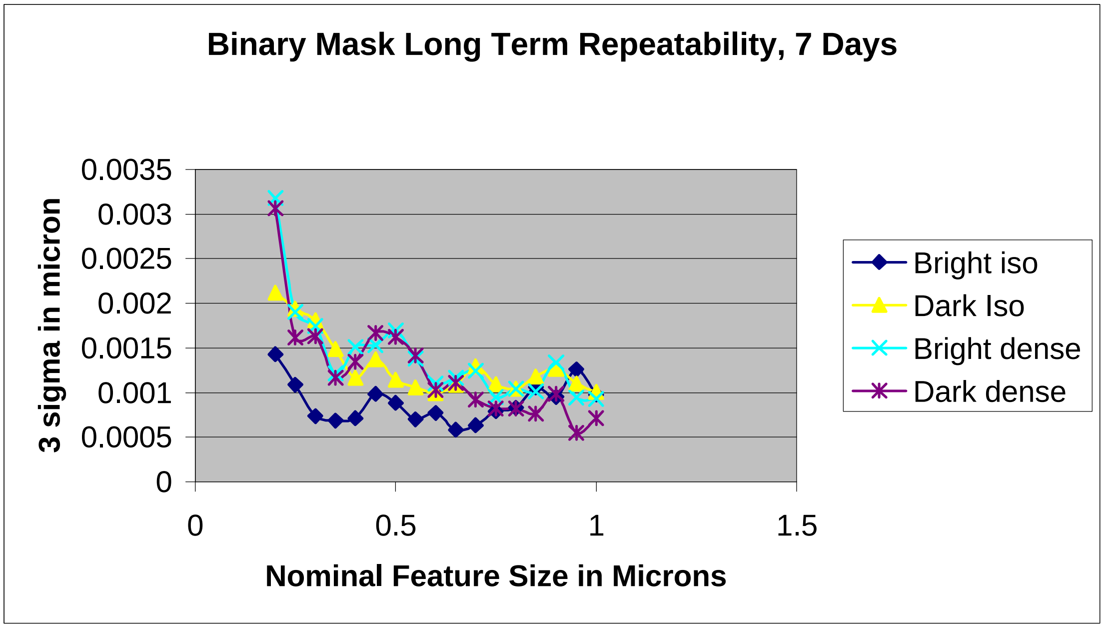

Figure 4

Figure 5 shows long-term dynamic contact measurement repeatability (7 days).

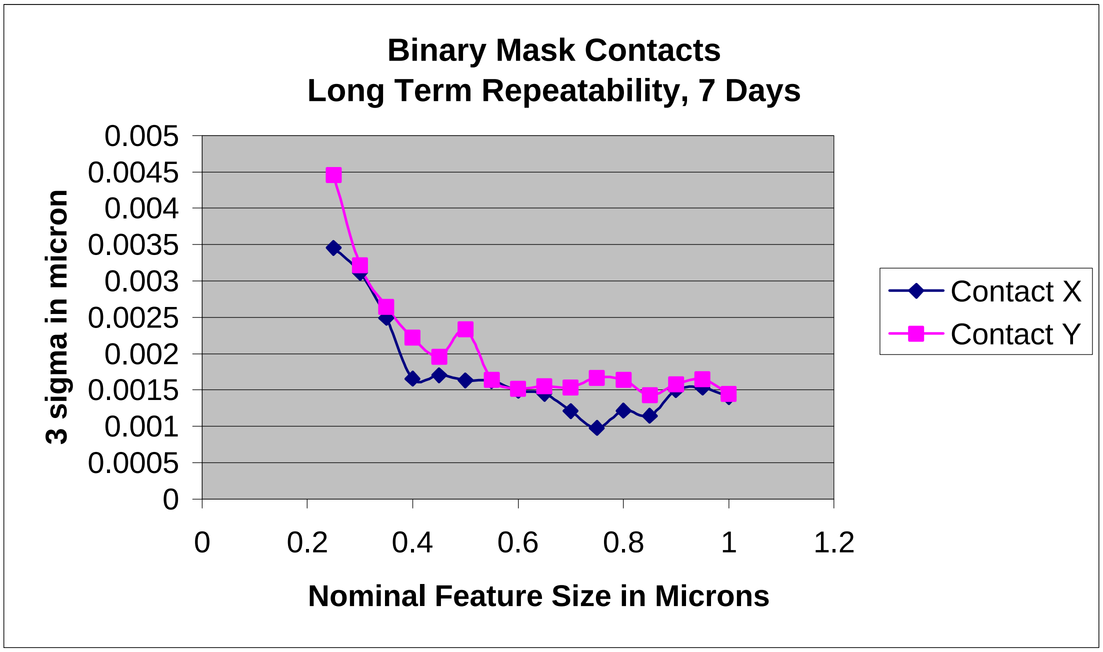

Figure 5

IV. Short and Long Term Repeatability Performance 193 nm ArF Phase Shift Mask (Static and Dynamic)

Figure 6 shows short-term repeatability on an ArF PSM Mask. The smallest contact measured on the ArF PSM mask was 0.3 microns. The average 3-sigma values of all measured contact holes are shown in Table 3.

Clear iso contact X	2,05 nm
Clear iso contact Y	2,50 nm

Table 3

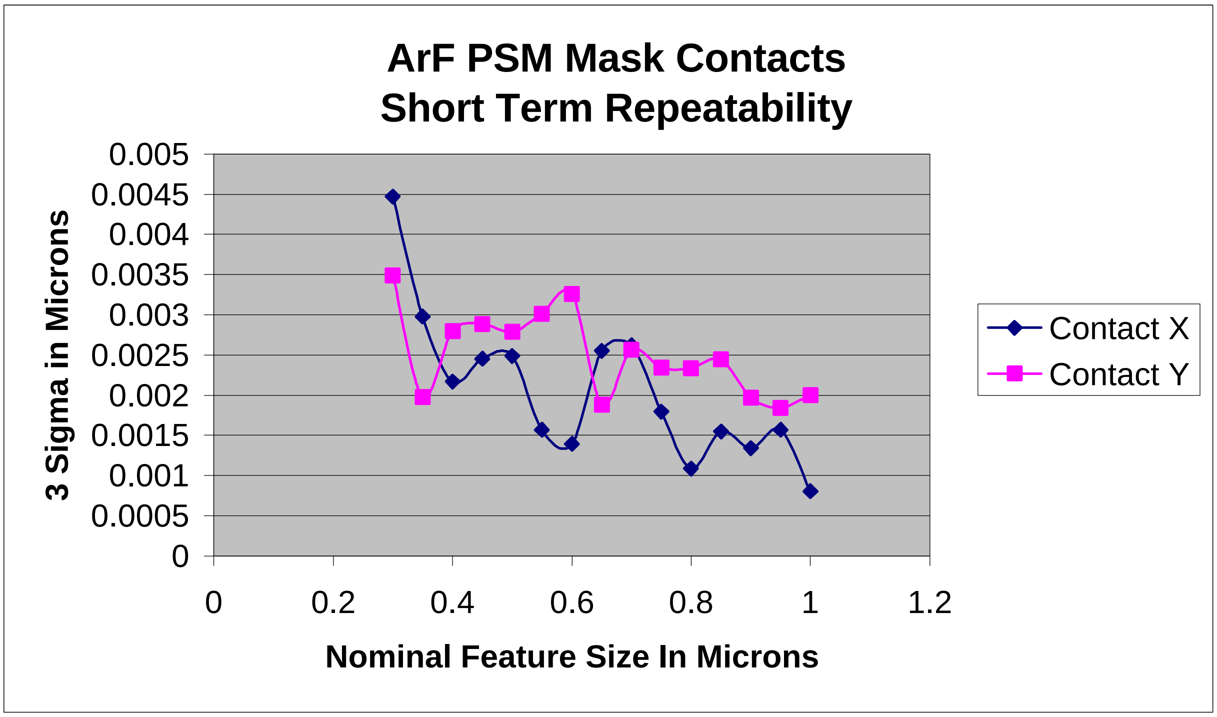

Figure 6

Figure 7 shows long-term performance on isolated and dense lines and spaces, clear and dark over a 7-day period

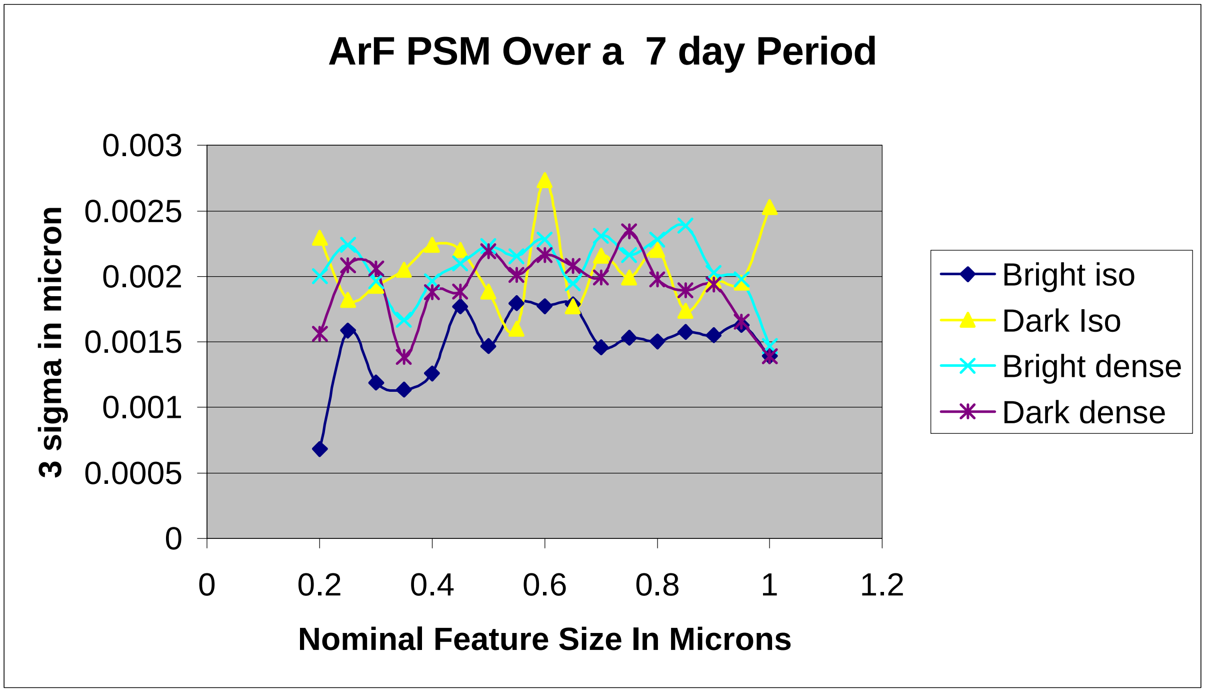

Figure 7

The ArF PSM also had an array of contacts on it that were measured dynamically 10 times. Figure 8 shows a 3D graph of the 6 x 6 array and Table 4 summarizes the 3 average 3-sigma repeatability for the contact measurements

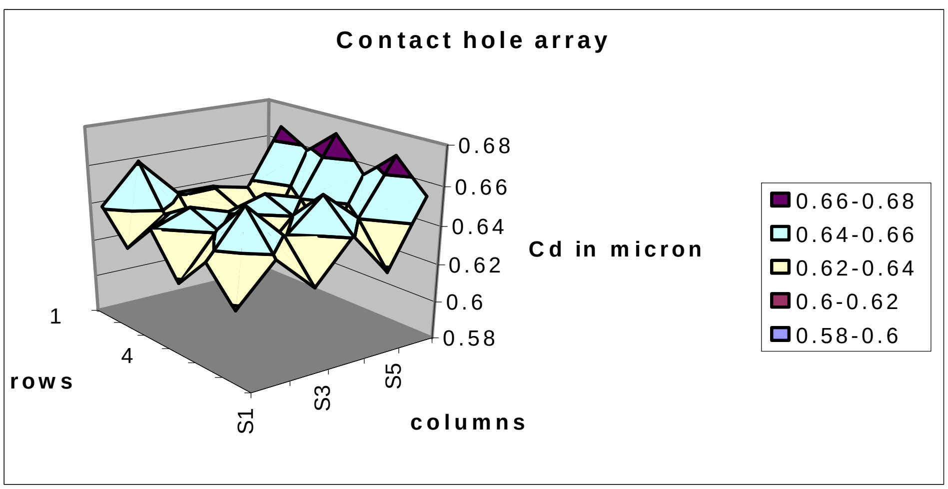

Figure 8

Contacts	Average 3s in nanometers
3 sigma X	1.6098
3 sigma Y	1.4866

Table 4

IV. Short and Long Term Repeatability Performance 248 nm KrF Phase Shift Mask (Static and Dynamic)

Figure 9 shows short-term repeatability on contacts (static).

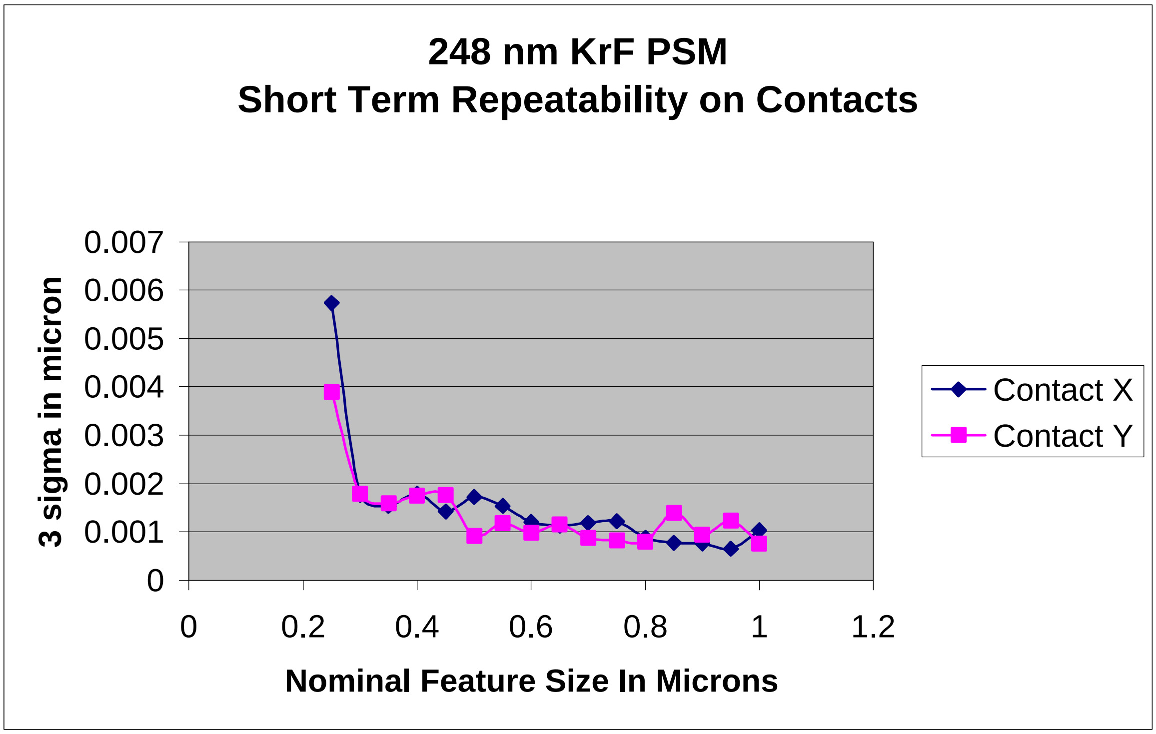

Figure 9

Table 5 shows the average 3-sigma repeatability on the contacts of the KrF mask.

Clear iso contact X	1.521nm
Clear iso contact Y	1.364 nm

Table 5

Figure 10 shows the short-term dynamic system performance (10 measurement loops) on nested and isolated clear and dark lines of the KrF phase shift mask.

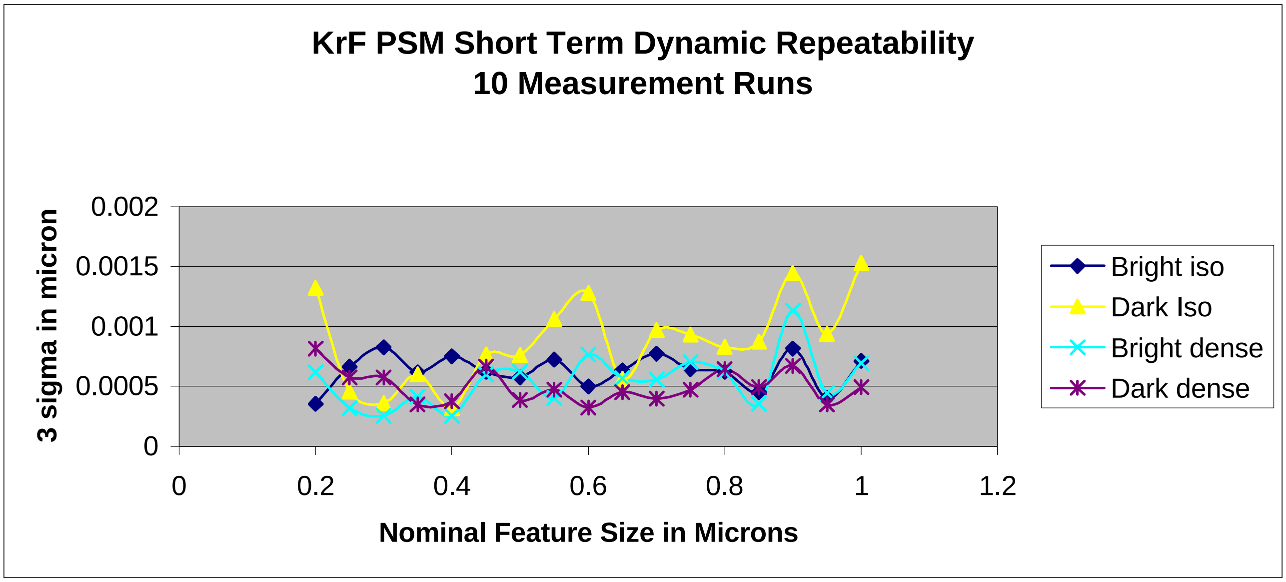

Figure 10

Table 6 shows the average 3-sigma values in nanometers for the Figure KrF isolated and dense lines and spaces. The average repeatability on lines and spaces isolated or dense is about 1nm 3 sigma.

Bright isolated	1,00725424
Dark isolated	0,98395235
Bright dense	1,06005547
Dark dense	1,02234566

Table 6

Long-term performance measured over a period of 8 days yields values generally below 3 nm, 3 sigma. We are currently investigating the root cause of the high values associated with the chrome or dark isolated lines as shown in Figure 11. Table 7 shows the average 3-sigma values in nanometers for all features measured features on the KrF mask.

Bright Isolated	2.33238
Dark isolated	2.61341
Bright Dense	1.73547
Dark Dense	1.85402

Table 7

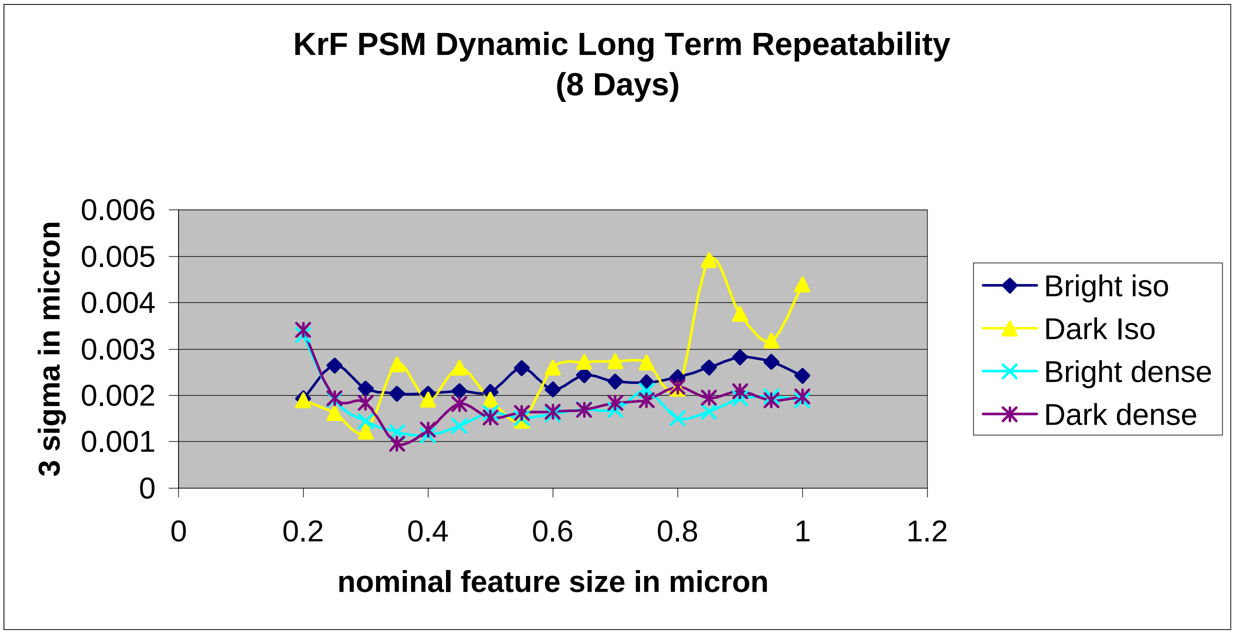

Figure 11

Contacts were measured on the KrF PSM for an 8-day period as well. Figure 12 shows the long-term repeatability results. Table 8 shows the average long-term repeatability of the contact measurements.

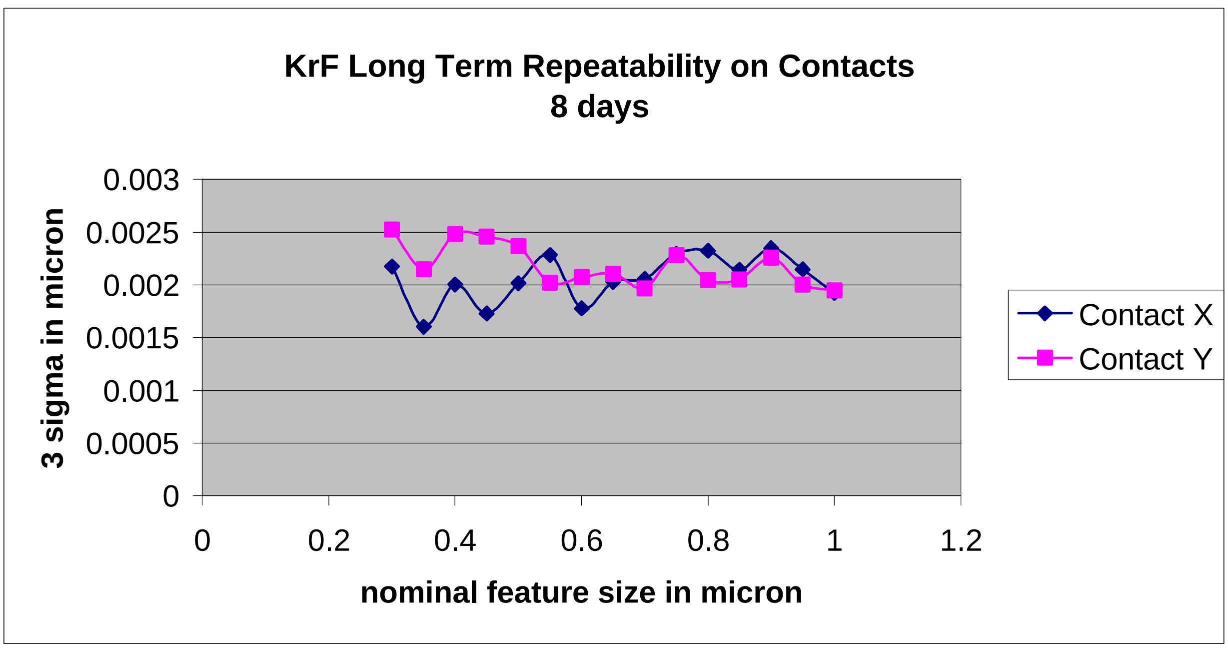

Figure 12

Clear iso contact X	1,928nm
Clear iso contact Y	1,79 nm

Table 8

V. Summary

Significant improvements in measurement repeatability performance on the LWM 270 DUV system have been achieved utilizing new hardware features and software improvements. The measurement uncertainty of contact features as well as nested lines and spaces have been dramatically reduced using the new algorithms. Long-term performance on binary and phase shift masks are now typically in the 1 to 2-nanometer range on many feature sizes. Features in the non-linear measurement range (200 to 300 nm) still exhibit degradation in repeatability performance.

Further improvements in software as well as new techniques for improving illumination and resolution will be implemented in the future.

VI. Literature

[1] First Results from a New 248 nm CD Measurement System for Future Mask and Reticle Generation
Gerhard Schlüter, Gerd Scheuring*, Jürgen Helbing*, Sigrid Lehnigk**, Hans-Jürgen Brück*
Leica Microsystems Wetzlar GmbH, P.O. Box 2040, D-35530 Wetzlar
**Mue*Tec GmbH, Wildermuthstrasse 88, D-80993 Munich
**Submicron Technologies GmbH, Wildermuthstrasse 88, D-80993 Munich
[2] Performance data of a new 248 nm CD metrology tool proved on COG reticles and PSM's
Gerhard Schluetera, Walter Steinberga, John Whitteyb aLeica Microsystems Wetzlar GmbH
Ernst-Leitz-Str. 17-37, D-35578 Wetzlar, Germany Phone: +49-6441-29-2465 Fax: +49-6441-29-2339
SPIE BACUS Symposium 2001, Monterey California
[3] Optical Mask Metrology of next generation lithography - Wolfgang Vollrath(a), Gerhard Schlueter (a) Gerd Scheuring (b)
Leica Microsystems Wetzlar GmbH, P.O. Box 2040, D-35530 Wetzlar
**Mue*Tec GmbH, Wildermuthstrasse 88, D-80993 Munich
EIPBN Conference in Washington DC 2001
[4] Schlueter, G., Brueck, H.-J., Birkenmayer, S., Falk, G., Scheuring, G., Walden, L., Lehnigk, S.: "A new UV capable photomask CD metrology tool" in Photomask and X-Ray Mask Technology VI, Hiroaki Morimoto, Editor, Proceedings of SPIE Vol. 3748, pp. 592-598 (1999)
[5] Schätz, Th., Hay, B., Walden, L., Ziegler, W.: "Development of an Algorithm for Monitoring of Pattern Fidelity on Photomasks for 0.2 µm Technology and Beyond Based on Light Optical CD Metrology Tools" in Mask Technology for Integrated Circuits and Micro-Components '98 (GMM-FB 25), pp. 99-107 (1998)
[6] Schlüter, Scheuring, G., Falk, G., Brück, H.-J., Schätz, Th. Lehnigk, S.: „Major Improvements in Mask CD Metrology: Enhanced Performance on Attenuated Phase Shift Masks, Corner Rounding Measurements, and Improved Measurement Automation" in European Conference EMC on Mask Technology for Integrated Circuits and Micro-Components 16 (GMM-FB 30), pp. 95-99 (1999), Munich