Performance data of a new 248 nm CD metrology tool proved on COG reticles and PSM's

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ABSTRACT

A new CD metrology system with 248 nanometer (nm) (DUV) illumination is the subject of this paper. The system configuration and major component improvements is described. Test measurements on chrome-on-glass (COG) and attenuated phase shift masks (Att-PSM) were performed demonstrating optical resolution of 100 nm for inspection and 200 nm for CD metrology. The test measurements also demonstrated improved CD linearity down to approximately 300 nm and long term repeatability performance in the 2 nm realm.

Keywords: CD metrology, mask metrology, CD linearity, optical resolution, 248-nm CD measurement tool, light optical measurement tool, 100-nm node

1. INTRODUCTION

The critical dimensions of patterns on photomasks are continuously shrinking. Simultaneously the CD specifications are becoming tighter to meet the total error budget required on the wafer. To extend the lifetime of optical steppers and optical scanners, huge efforts have been made to extend the limits of optical lithography. To keep pace with these developments and to be able to verify the tighter mask specifications, CD metrology equipment has moved from the current state-of-the-art 365 nm to 248 nm (DUV) illumination to achieve improved optical resolution and to extend the CD linearity range.

2. THE DUV CD METROLOGY TOOL

2.1 Improvements for key components

The numerical aperture upper limit has limitations when working in air. Using an immersion lens with water and a numerical aperture greater than one is not a practical solution at this time. Decreasing the Rayleigh function k-factor is either not applicable to optical microscopy or currently not technically practical. To improve the optical resolution of the Leica LWM 250 UV CD metrology system it was necessary to reduce the illumination wavelength down to the 248 nm DUV range.

The decrease in illumination wavelength to DUV required new technical solutions for light sources and filters, materials for optical components, new lens designs, and detectors with DUV enhanced sensitivity. Additional improvements were necessary to reduce influences that could deteriorate the measurement precision and stability. This was in addition to improvements in CD linearity.

The spectral intensity distribution of the HgXe lamp for the 248 nm wavelength is less than 10% of the I-line wavelength of 365 nm. Only recently have arc lamps become available showing sufficient stability over time. Alternative solutions using Laser illumination could have solved the intensity problems, but would also have generated new problems such as interference effects from the coherent light source.

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The lower intensity of the illumination sources required optical detectors with a DUV enhanced sensitivity at reasonable frame rates that have just recently become available.

The largest obstacle that Leica Microsystems had to overcome for entering the DUV microscopy was the development and manufacturing of DUV optics, including thin film coatings for reflection reduction and beam splitting. To correct image aberrations over a finite spectrum range and field of view, optical materials with various dispersions and different diffraction indices with reasonable transmission in the required spectrum range were required. The small spectrum range around the 248 nm wavelength in conjunction with few applicable optical materials necessitated an objective design with more lenses to correct for aberrations as compared to traditional white light objective designs. To design a DUV lens with the additional goal of laser autofocus capability at 903 nm was considered to be a near impossible goal at the beginning of the development[1]. In addition to newly designed imaging optics, the illumination optics for transmitted light DUV measurements necessitated the development of a new condenser lens.

First attempts with cemented optical components for the 150x/0.90/248nm DUV objective showed excellent performance with high contrast and an optical resolution in the 80 nm range. Unfortunately all the known optical cements used for fixing subgroups of optical components proved to be sensitive in the long term to the DUV illumination intensity that led to a degradation in transmission over time. To overcome this problem a technique called Air-Space Technology (AT) was applied, splitting up cemented lens groups by small air spaces. The difficulty of this technology is sensitivity to extremely tight tolerance mechanical requirements and strong internal reflections at lens surfaces. The Leica DUV 150x/0.90/248nm AT objective is the first worldwide non-cemented DUV objective corrected for a finite spectral bandwidth and autofocus capability[2].

Last but not least the complete tool setup had to be re-designed to reduce any thermal or vibration effects on the measurement core components. To achieve this most of the heat generating, power consuming components were moved into a separate electronics rack which also contains the operator console leaving the microscope components on a separate two-fold vibration isolated base frame.

2.2 Leica LWM250 DUV configuration

Fig. 1: Leica LWM250 DUV

The new Leica LWM250 DUV is based on the field–proven predecessor LWM250 UV. It is comprised of two main components, the measurement unit and the electronics rack (Fig. 1).

The key components of the measurement unit are the DUV microscope with a 100 W 248 nm (DUV) Hg/Xe light source together with a notch filter for 248±8 nm wavelength and an illumination light path optimized for CD measurements in transmitted light. A halogen illumination for coarse positioning and alignment in reflected light mode in also used. The system uses a laser autofocus capable DUV 150x/0.90/248nm AT objective for fast and accurate auto-focusing, resulting in high throughput. A sliding mask holder loading system is used for secure loading and unloading of reticles. The scanning stage is equipped with a linear scale encoder for fast and accurate positioning of features to be measured. A DUV-enhanced digital camera with a reduced pixel size of 22.5 nm is used in conjunction with the measurement objective for enhanced measurement capabilities. All of these components are mounted on a two-fold vibration isolation system.

The electronics rack contains almost all the necessary power supplies, control electronics for system operation and networking, it also serves as an operator console with keyboard, mouse and joystick. The electronics rack can be positioned on either side of the measurement unit and can be separated from it by up to 2.5 m allowing for flexibility in system setup.

The Windows NT 4.0™ graphical user interface allows for easy job setup and system operation. Job setup information can be imported by either Leica LMS MF2/MF3 data input format or ASCII script files. The most flexible way of job setup entails using the system's macro recorder. It is also possible to download defect detection files from various defect detection, classification, and analysis systems for review and re-classification.

3. PERFORMANCE DATA

3.1 Optical resolution

Theoretically the optical line resolution of an objective with a numerical aperture of 0.90 should be close to 85 nm when using 248 nm (DUV) illumination, compared to 125 nm for the state-of-the-art 365 nm (I-Line) wavelength. Even though the mechanical tolerances are extremely tight for a laser autofocus capable DUV AT objective, the optical resolution achieved has proved to be very close to the theoretical limits. For CD measurements a drop in intensity between two separated and optically resolved lines to a level of much lower than 74% as used for the definition of optical resolution is required. Usually the threshold is set to 50% of the maximum intensity for CD measurements. This is the reason for the difference in line resolution for optical inspection compared to the practical limit for line CD metrology.

Fig. 2 clearly shows the improved optical resolution on 150 nm line and space patterns (300 nm pitch) when using DUV illumination in combination with the 150x/0.90/248nm AT objective. This is compared to the current state-of–the-art I-Line illumination using a 150x/0.90/365nm objective. In I-Line mode the features are not clearly resolved enough for critical dimensions to be measured whereas in DUV mode the features show a high enough contrast for CD measurements.

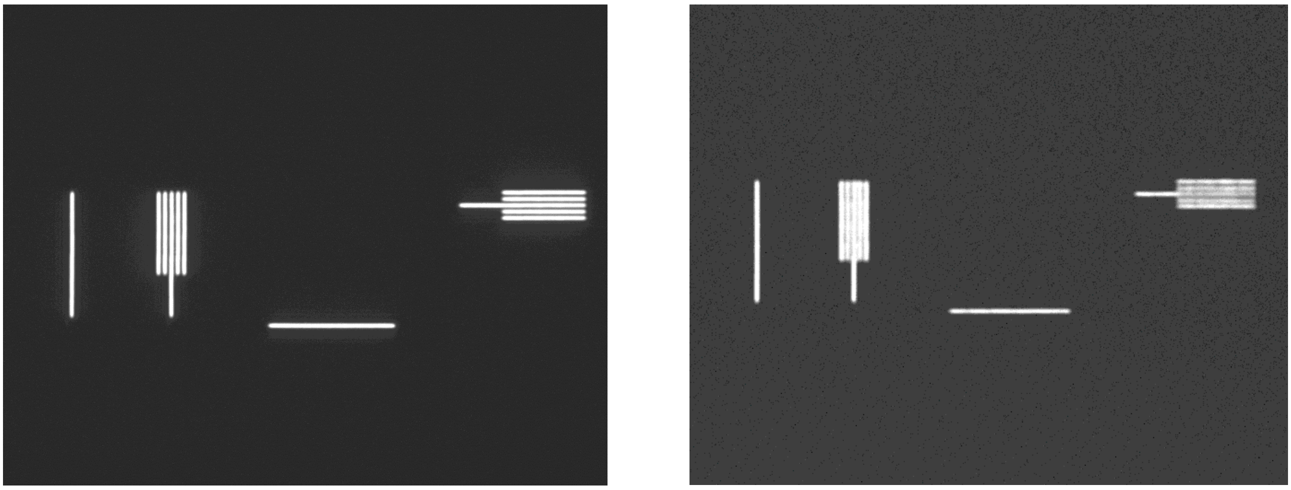


Fig. 2: Improved optical resolution performance proved on 150 nm L&S COG pattern (300 nm pitch)
Left: 248 nm (DUV) illumination
150x/0.90/248nm AT objective
Right: 365 nm (I-Line) illumination
150x/0.90/365nm objective

3.2 CD linearity

One of the main goals for the new DUV tool which is directly related to the optical resolution has been to extend the range of linearity for CD measurements down to smaller feature sizes compared to an I-Line tool. From earlier experiences with white light and I-Line CD measurement systems it is known that the lower limit for linear CD measurements is approximately two times the theoretical point resolution Δx for inspection according to equation (1).

$$\Delta x = k * \frac{l}{NA} \tag{1}$$

Therefore it was expected that the DUV CD Measurement tool would be able to move to the limit of the CD linearity range that was calculated to be approximately 300 nm.

Measurements were performed on COG features in the range of 0.2 – 3.0 µm using isolated lines, single lines with single spaces on each side, and lines out of dense line and space patterns. The DUV CD measurement data was compared with results achieved on a Holon CD-SEM. For comparison purposes, features in the range of 0.3 – 3.0 µm out of the same group of structures were measured on a Leica LWM250 UV I-Line tool. The optical measurements were performed with identical regions of interest (ROI) and threshold settings for both the DUV and I-Line measurements. Fig. 3 shows the deviations without offset correction between optical CD measurements using LWM250 DUV and the Holon CD-SEM data (lower group of curves), while the upper group of curves shows the deviations between the LWM250 UV and the Holon CD-SEM data.[3]. The graph clearly shows the improvement in CD linearity for DUV measurements down to the 0.3 µm area whereas for UV measurements the lower limit in CD linearity is closer to 0.5 µm.

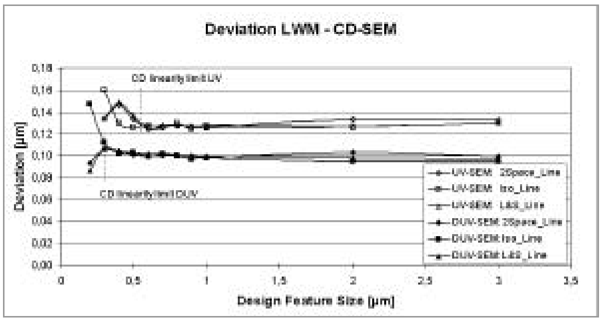


Fig. 3: CD linearity with UV and DUV illumination

Fig. 4 shows CD measurements vs. nominal feature sizes on a different COG mask. Measurements were done on feature sizes down to 0.1 µm and 0.15 µm nominal values for isolated clear and chrome lines and 0.2 µm sizes for dense clear and chrome lines. The graph shows a smooth linear behavior down to nominal features sizes of 0.3 µm or even slightly below. Fig. 5 shows the deviations between DUV CD measurements and nominal feature sizes for isolated and dense clear and chrome patterns. There is an almost constant bias for optical CD measurement data compared to nominal feature sizes of +60 nm for clear features independent of isolated or dense, and of –65 nm and –80 nm for isolated chrome and dense chrome patterns down to feature sizes of 0.3 µm.

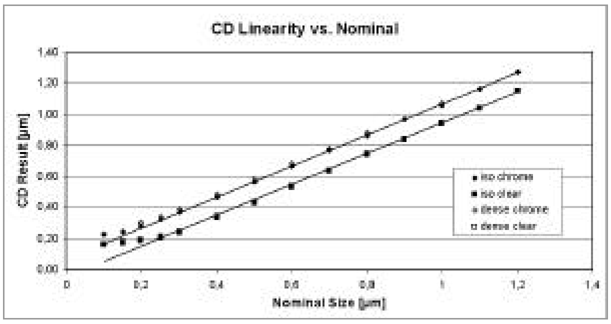


Fig. 4: CD measurement vs. nominal for isolated and dense clear and chrome features on COG

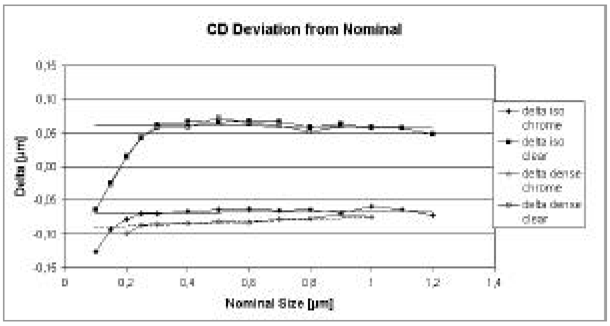


Fig. 5: Deviations between DUV measurements and nominal sizes of isolated and dense clear and chrome features on COG

Attenuated PSM (Att-PSM) CD’s of clear and dark features were measured in the range of 0.25 µm to 0.9 µm and compared with nominal feature sizes. Structure groups were measured in the upper left (UL), upper right (UR), center

(CE), lower left (LL), and lower right (LR) part of the reticle in both, X and Y directions. The results shown in Fig. 6 and 7 assume an almost linear behavior down to 0.4 µm or even below.

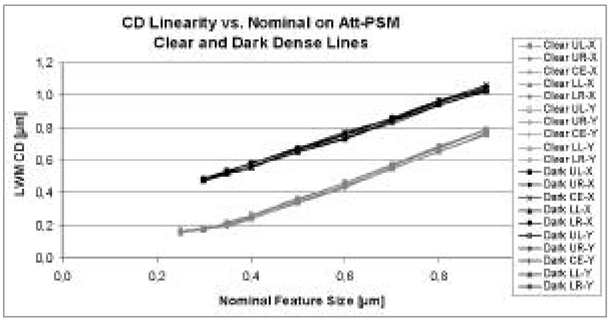


Fig. 6: CD-Linearity vs. nominal feature size for clear and dark dense lines on Att-PSM

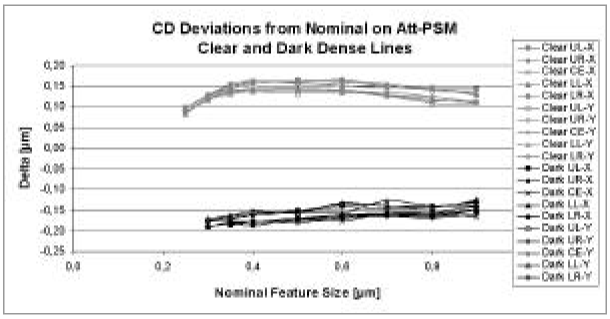


Fig. 7. CD deviations from nominal feature size for clear and dark dense lines on Att-PSM

3.3 CD Repeatability

The CD repeatability performance was tested on both, the Leica Standard MZD Test mask (COG) and on an Att-PSM.

The Leica Test mask was used for testing the long-term repeatability performance of the DUV tool. Features of both polarities (clear and chrome) between 0.3 to 4.6 µm were measured within a measurement loop (dynamic measurement) for three consecutive days and 30 loops per day. At the end of each day the test mask was unloaded, re-loaded and re-aligned on the following day. All measurements were performed without a multipoint calibration; a basic pixel pitch calibration was used.

Fig. 8 shows the individual deviations from the corresponding mean values of the 3-day repeatability performance test for clear and chrome lines of 0.3 – 4.6 µm sizes measured in the x direction. Statistical data corresponding to Fig. 8 are presented in Fig. 9 demonstrating excellent 3-day long term performance for a 99.7% confidence level to be in the 2 nm range or lower.

To check whether feature sizes smaller than the specified 200 nm could be measured with reasonable repeatability performance, clear lines of a nominal size of 150 nm were measured over a 60 hour period taking CD measurements every 6 minutes (Fig. 10). The statistics of the data presented in Fig. 10 results in 2.5 nm for a 99.7% confidence level with a total range of 5.2 nm over 60 hours.

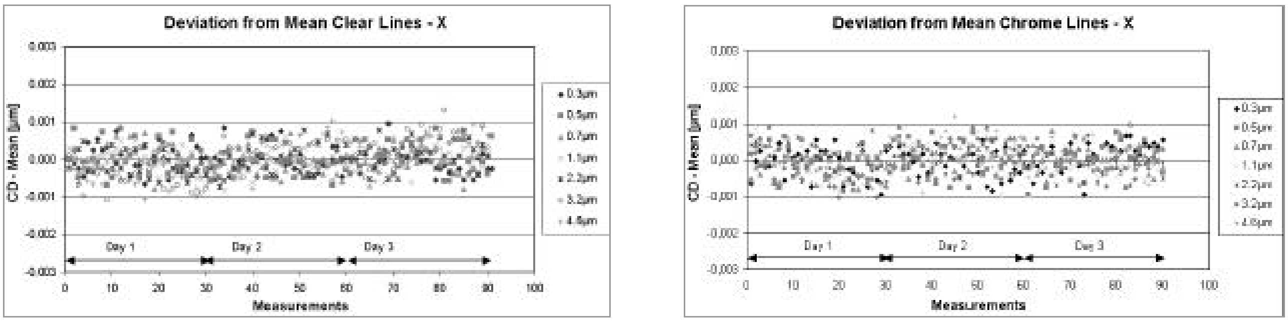
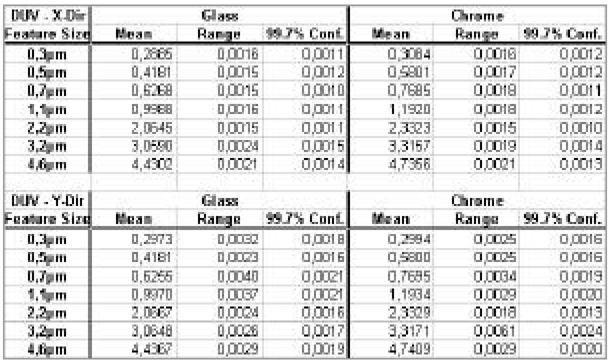


Fig. 8: Three-days long term repeatability showing CD deviation from mean values for
Left: clear lines in X direction and
Right: chrome lines in X direction



DUV - X-Dir	Glass			Chrome		
Feature Size	Mean	Range	99.7% Conf.	Mean	Range	99.7% Conf.
0,3µm	0,2865	0,0016	0,0011	0,3084	0,0016	0,0012
0,5µm	0,4181	0,0015	0,0012	0,5801	0,0017	0,0012
0,7µm	0,6268	0,0015	0,0010	0,7685	0,0018	0,0011
1,1µm	0,9988	0,0016	0,0011	1,1920	0,0018	0,0012
2,2µm	2,0645	0,0015	0,0011	2,3323	0,0015	0,0010
3,2µm	3,0590	0,0024	0,0015	3,3157	0,0019	0,0014
4,6µm	4,4302	0,0021	0,0014	4,7358	0,0021	0,0013

DUV - Y-Dir	Glass			Chrome		
Feature Size	Mean	Range	99.7% Conf.	Mean	Range	99.7% Conf.
0,3µm	0,2973	0,0032	0,0018	0,2984	0,0025	0,0016
0,5µm	0,4181	0,0023	0,0016	0,5800	0,0025	0,0016
0,7µm	0,6255	0,0040	0,0021	0,7695	0,0034	0,0019
1,1µm	0,9970	0,0037	0,0021	1,1934	0,0029	0,0020
2,2µm	2,0667	0,0024	0,0016	2,3329	0,0018	0,0013
3,2µm	3,0648	0,0026	0,0017	3,3171	0,0061	0,0024
4,6µm	4,4367	0,0029	0,0019	4,7409	0,0029	0,0020

Fig. 9: Statistical data for 3-days long term performance

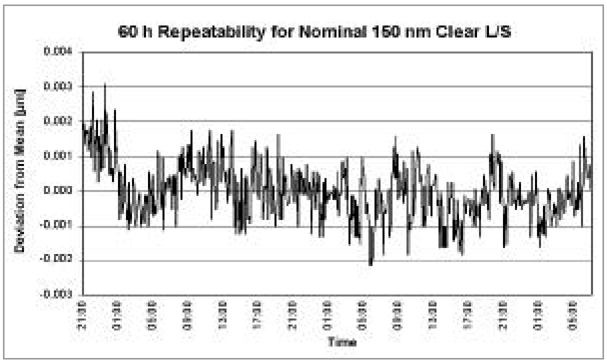


Fig. 10: Three days long term repeatability showing deviation from mean values for chrome lines

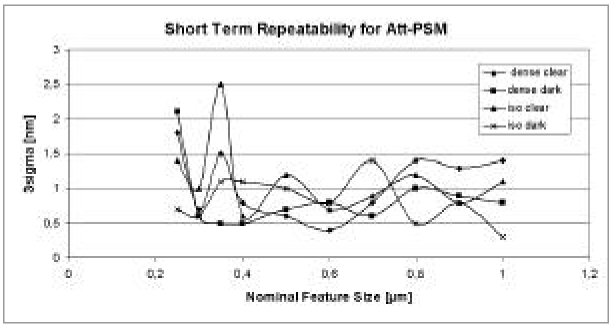


Fig. 11: Sort term repeatability for different feature sizes measured on Att-PSM

Preliminary tests to check the tool performance for short term repeatability on an Att-PSM led to the results shown in Fig. 11. Isolated and dense structures with feature sizes in the range of 250 nm to 1 µm nominal were measured 10 times in a measurement loop using a special Halftone-PSM algorithm for intensity profile evaluation and CD calculation. Assuming a Gaussian distribution for the ten measurements the 3 sigma values in Fig. 11 for the short term repeatability on an Att-PSM are almost identical to the total range values of the ten measurements.

4. CONCLUSIONS

Leica Microsystems' new 248 nm CD metrology system the LWM250 DUV with the world's first laser autofocus capable DUV objective in air-space technology was described. Optical resolution of better than 100 nm was demonstrated for inspection and the capability of measuring features as small as 200 nm was shown. Dense features as small as 150 nm show a high enough contrast that is sufficient for CD measurements with remarkable repeatability.

Improved optical resolution has allowed the extension of CD linearity measurements to be reduced to 300 nm, versus 500 nm for UV CD systems. This was demonstrated on isolated, semi-dense, and dense patterns of a COG reticle for which CD-SEM results were available. For the Att-PSM no CD-SEM data was available. Therefore the CD measurement data on the Att-PSM was compared to nominal feature sizes showing a reasonable linear behavior down to 0.3 µm for dark features and a slightly worse linearity limit for clear features.

The long term repeatability performance of the Leica LWM250 DUV was tested using a three-day test on a COG reticle and showed results in the range of 2 nm with a 99.7% confidence level. For 150 nm clear features, a 60-hour test demonstrated a 3-sigma repeatability performance of 2.5 nm. First results on an Att-PSM show short term repeatability to be in the 2.5 nm range for features down to 0.25 µm.

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