BACUS 2007 6730-214

Mask CD Control (CDC) with Ultrafast Laser for Improving Mask CDU Using AIMS™ as the CD Metrology Data Source

Guy Ben-Zvi[1], Eitan Zait[1], Vladimir Dmitriev[1], Erez Graitzer[1], Gidi Gottlieb[1], Lior Leibovich[1]
Robert Birkner[2], Klaus Boehm[2]Thomas Scheruebl[2]

1. Pixer Technology, 44 Maale Camon Karmiel 21613 Israel
Phone +972 4 9088600 Fax +972 4 9088666

2. Carl Zeiss SMS GmbH, Carl Zeiss Promenade 10, 07740 Jena, Germany,
Phone: +49 3641 642881 Fax: +493641642938

Keywords: CD control, CDC, CDU, Aerial Imaging, AIMS, Shading Elements, Ultrafast Laser, Photomask,

ABSTRACT

CD uniformity control by ultrafast laser system writing inside the bulk of photomasks has previously been shown to be an effective method for local CD Control (CDC) [1].

Intra-field CD variations correction has been implemented effectively in mask-shops and fabs based on CDC SEM [2, 3] and OCD as the CD data source. Using wafer CD data allows correction of all wafer field CD contributors at once, but does not allow correcting for mask CD signature alone. In case of a mask shop attempting to improve CDU of the mask regardless of a particular exposure tool, it is a better practice to use mask CD data by itself as the CD data source.

We propose using an aerial imaging system AIMS™45-193i as the mask CD data source for the CDC process.

In this study we created a programmed CD mask (65nm dense L/S) with relatively large CD errors. The programmed CD mask was then measured by AIMS™45-193i (AIMS45) which defined the CDU map of the programmed CD mask. The CDU data from AIMS™45-193i was then used by Pixer CDC101 to correct the CDU and bring it back to a flat almost ideal CDU.

Results

1. AIMS™45-193i managed to map the full mask CDU with a resolution of 0.5 nm.
2. The CDC101 managed to correct the CDU based on the AIMS™45-193i data from Range 5nm and 3S 4nm down to Range<1.5nm and 3S< 1.0nm

Conclusions

By using AIMS™45-193i and CDC101 alone, without any wafer CD data, the mask CDU can be improved >70% and mask contribution to wafer CDU can be brought down to <1.0 nm 3S.

INTRODUCTION

Target

The target of this study was to prove the feasibility of correcting mask CDU errors by the CDC process based on mask aerial imaging CD data, without printing a real wafer and measuring its CD.

The reasoning behind this approach to CD control is that in many cases the mask shop wishes to correct the mask CDU without relying on wafer print results. This could be either because the mask shop is a merchant shop with no access to wafer printing tools, or because the mask is intended for several exposure tools and is not dedicated to one tool. In this case it is a better practice to correct "mask only" CD errors instead on wafer print CD errors which may make the mask optimally suited for one exposure tool (the one used for generating the CDU data) but non optimal for other exposure tools.

In order to characterize the net effect of the CDC process and the aerial imaging process we used a very flat CDU mask and artificially introduced programmed CD errors by using the CDC tool itself.

The programmed CD mask was then sent for CD mapping by AIMS™45-193i and the CDU data measured by the AIMS™ tool was used to correct the mask to a close to ideal CDU. Finally the corrected mask was measured again on AIMS™45-193i in order to prove the ability to close the loop of CDU improvement without printing.

Herein we describe the experiment and its results

EXPERIMENTAL

Materials and methods

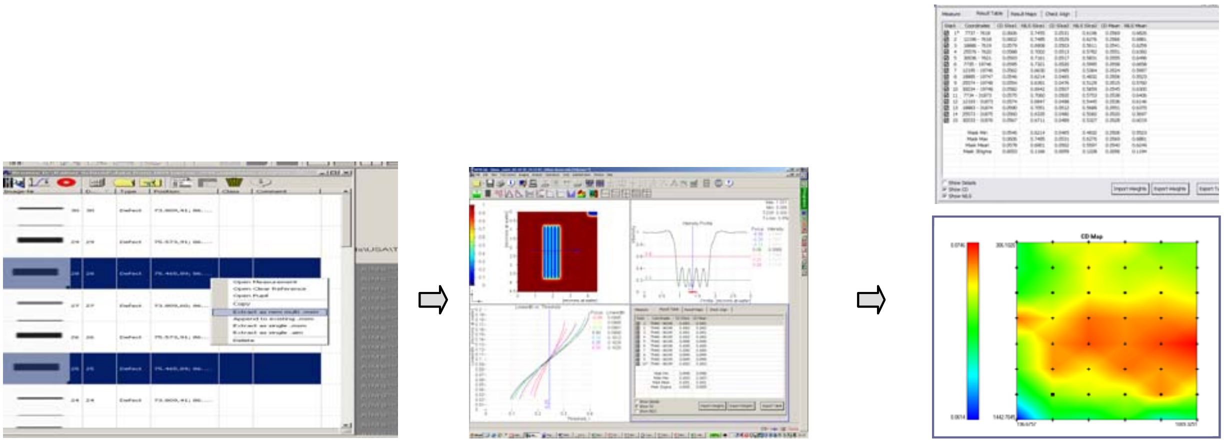
Test mask- Pixer 65nm test mask. The mask contains a combination of vertical and horizontal dense L/S patterns and isolated lines. For sake of simplicity we chose to measure and correct the dense 65 nm vertical pattern only. The mask was a binary COG 6" mask made by Toppan Photomask in Dresden. The mask had a very flat CDU to begin with (Average of 130 CD SEM points- 65.6nm (on wafer level), range 1.33nm, and 3S 0.72nm). The mask was pellicalized.

AIMS™45 – 193i tool. For more than 15 years AIMS has been a well established method in the mask shop [6]. In an AIMS tool, a portion of the mask is illuminated under the same conditions (NA, sigma settings) as in the scanner. The light diffracted by the mask is gathered by an objective lens which magnifies the image on a CCD camera. Thus, the CCD camera sees the same aerial image as the wafer does. The classical application of AIMS is defect evaluation concerning the impact on wafer prints. If a defect is not visible in the AIMS tool it will not print on the wafer. The AIMS can read the coordinate files of the most common inspections tools. Given the coordinates the tool moves automatically to the defect location, and then the user can review the defect and analyze critical dimension (CD), transmission or process window.

Another important application is the analysis of mask CD uniformity (CDU). By using the software plug-in called “CD map”, the user can import a coordinate list and measure the CD of given coordinates on the mask. With these coordinates a CDU map of the mask is generated. As the AIMS uses the same illumination conditions as a scanner AIMS sees the CD “with scanner eyes”. By using the CDU map the user can differentiate the contribution of mask effects to the CDU signature from resist and scanner effects. Due to the large working distance the AIMS can measure CDU through pellicle which allows also the application of AIMS in the Wafer Fab.

The AIMS™45–193i is the newest tool generation which has been currently introduced in the market[7]. The AIMS™ 45–193i tool has been developed on a new mechanical platform which together with a thermal controlled measurement chamber provides extremely stable conditions for measurements. The improved stability results in improved values for CD repeatability which is important for CDU metrology applications. Besides the tool has a newly designed 193nm optical beam line, consisting of objective lens, imaging unit and illumination unit. The illumination unit supports various kinds of off-axis illumination schemes used in immersion scanners which can be combined with linear (x, y direction) or azimuthal polarization in order to enhance contrast. Finally, the tool is equipped with the new Zeiss proprietary vector effect emulator which allows emulating the contrast of aerial images in resist which are formed under high angles. The scanner equivalent variable NA from 0.75 to 1.4 allows the emulation of a wide range of dry and immersion scanners.

CDU measurements using AIMS™: For CDU measurements an optional SW plug-in called “CD-map” has been developed. The CD-map function [8] allows measuring fully automatically the CDU over the whole reticle for repeating features. The user only inputs a coordinate list of the measurement points and selects a fixed threshold value for determining the CD. The tool then automatically moves to each measurement point, takes data reading, compares to the threshold and generates a CD map of the mask. Figure 1 describes the process for generating a CDU map on AIMS™



Get AIMS data by coordinate list and apply Global CDU Map software plug-in to AIMS™ data.

Define threshold one time for CD value, tool applies threshold automatically to other measurements

Data are displayed by generating a color-coded CDU map or a table.

Figure 1

CD Control tool- in this study we used Pixer Technology CDC101 demo tool in Pixer demo lab in Karmiel Israel. The CDC101 tool utilizes an ultrafast femto second laser to write intravolume shading elements inside the bulk of the mask. The laser writing is done through the backside while the mask is faced pattern and pellicle down. By adjusting the density of the shading elements the light transmission through the mask is locally changed so that when printed on an exposure tool the CDU on wafer is improved. A detailed description of the CDC101 tool and its principle of operation can be found in [4]. Also a deep discussion of the CDC101 tool can be found in [5] **Performance comparison of techniques for intra-field CD control improvement** which is being presented in this conference by R. Pforr et al. Figure 2 describes a typical process flow of the CDC101 tool where the mask CDU data can come from wafer (CDSEM or OCD) or mask (AIMS45).

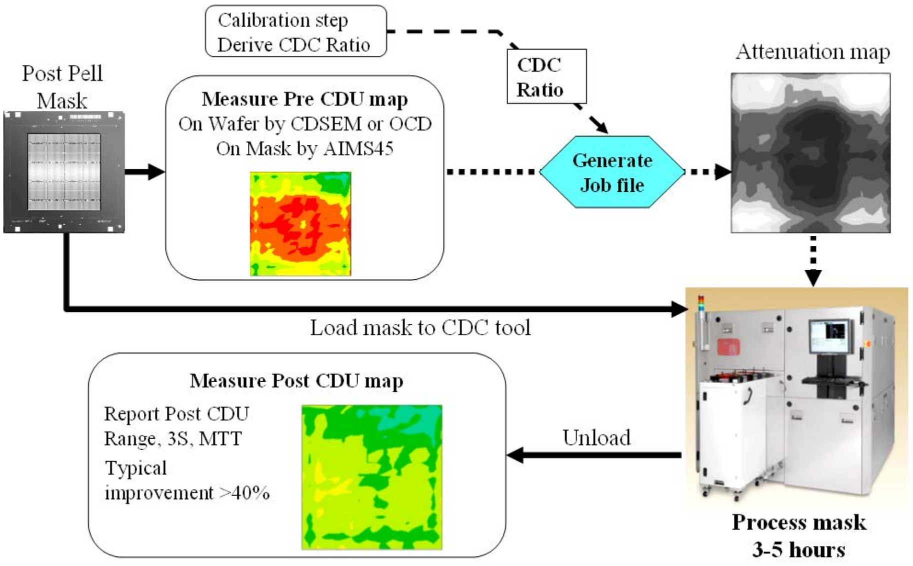


Figure 2

Design Of Experiment (DOE)

The study included 4 phases:

Phase 1 programmed CD mask preparation- The mask area was divided to 130 cells. 120 cells were treated for programmed CD errors and 10 cells were kept as control. By using the CDC101 tool we applied gradual attenuation from 0.0% (control) up to 5.0% in steps of 0.25%. Figure 3 describes the DOE of the programmed CD mask.

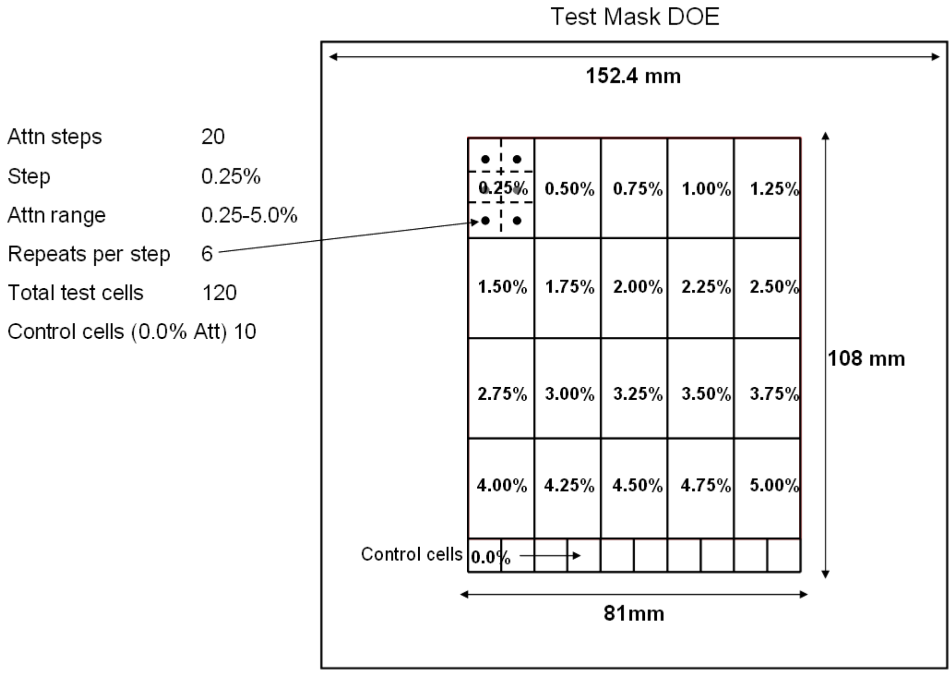


Figure 3

Phase 2, **aerial imaging CD measurment**- The programmed CD mask was measured by AIMS™45-193i and a CDU map was generated. The first measurement point in the first cell has been used as a reference point to determine the threshold for a target CD of 65nm at wafer level. This threshold was used for determining the CD of all other measurement points. The full mask (130 cells) measurment was repeated 3 times to represent 3 field exposures. The average of the 3 fields was used as pre CDC data.

Phase 3, CD corrections- The output data of AIMS™ 45–193i was used as input data for the CDC101 which applied an attenuation map to control for the measured CD errors.

Phase 4, CDU verification by aerial imaging- The mask was measured again by AIMS™45-193i and a post map was generated.

CD measurment conditions- All CD maps were measured on vertical dense line space patterns of 65nm. Illumination conditions on AIMS™45–193i: Unpolarized Dipole 65% NA 0.93 Sigma 0.97.

RESULTS AND DISCUSSION

Results

Phase 1- The programmed CD mask was written successfully. The CDC101 built in DUV transmission measurment system reported very good correlation between the programmed and measured attenuation levels. Figure 4 shows the verification of the attenuation written in the mask for the programmed CD step. Note that the slope of the correlation graph is not exactly 1.0 because measurment of transmission over dense pattern introduces a bias to the result. Nevertheless the linearity is very good and R^2 close to 1.0 so we conclude that the programmed CD pattern is correct.

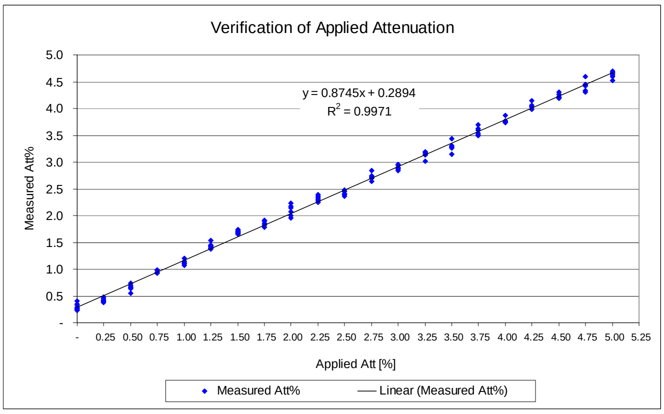
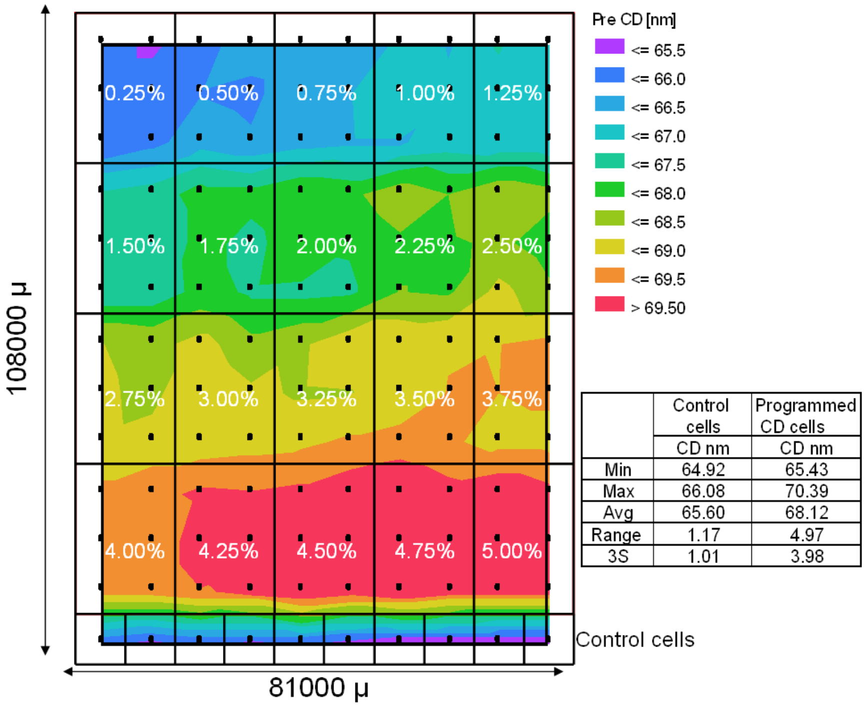


Figure 4

Phase 2- AIMS™45-193i managed to measure the CDU map with repeatability of <0.5 nm. The average CD was measured 68.12nm the range 4.97nm and 3S 3.98nm. The control area was also measured and confirmed that the CD of the mask was 65.6nm, which is exactly the same as measured by CD SEM.

Figure 5 shows the CD map as measured by AIMS™45–193i with the programmed CD cells superimposed. Each dark spot on the map designates a CD measurment point.



	Control cells	Programmed CD cells
	CD nm	CD nm
Min	64.92	65.43
Max	66.08	70.39
Avg	65.60	68.12
Range	1.17	4.97
3S	1.01	3.98

Figure 5

Figure 6 shows the correlation between the applied attenuation and the measured CD on the programmed CD mask. By knowing this calibration ratio which we call the CDC Ratio (CDCR) we could now decide how to correct the CD. The CDCR was found to be 0.87 nm/ %Att

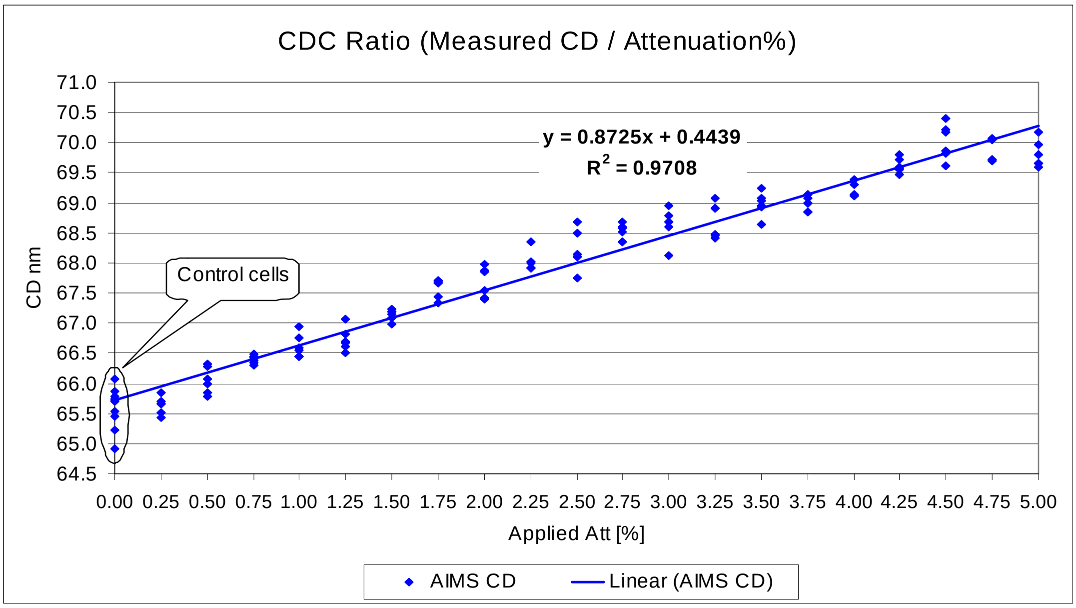


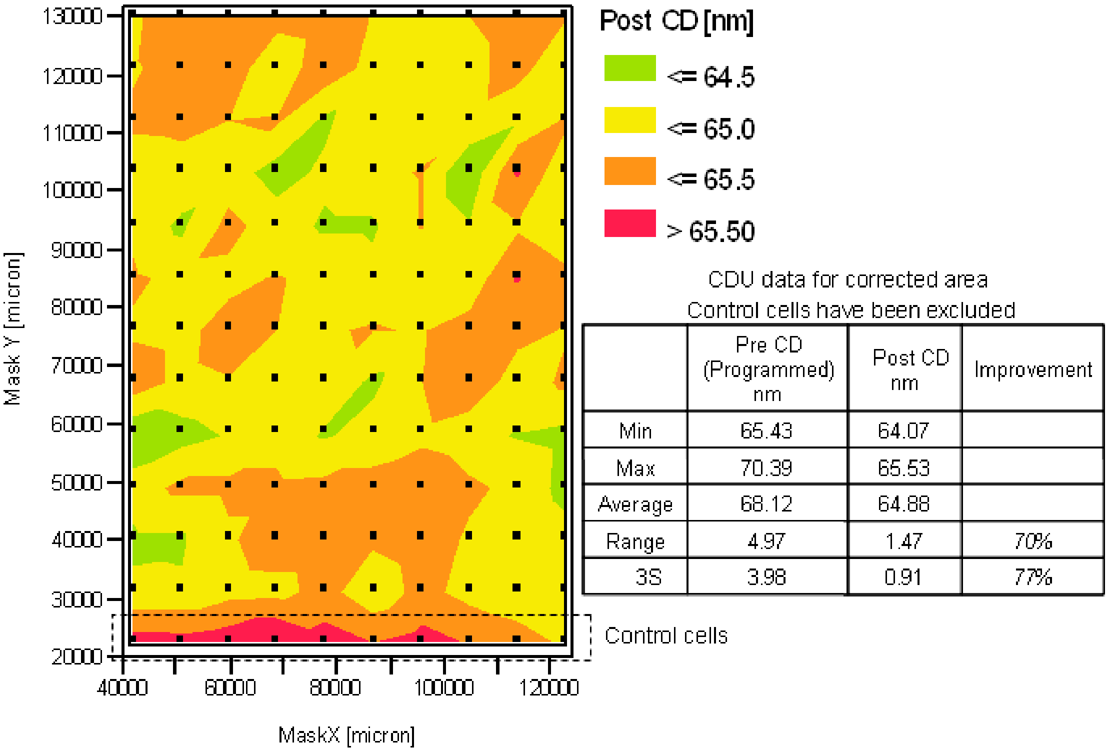
Figure 6

Phase 3

The Pre CDU map generated by AIMS™ was divided by the CDCR of 0.87 nm/Att%. As a result an attenuation map and a job file for the CDC101 were created. The mask was processed on the CDC101 tool accordingly with each point on the mask receiving an attenuation so as to bring its CD to the target, which is the point of lowest transmission on the map or highest CD value on the map (Note: CD was measured on opaque lines which means that CD goes up as the dose and transmission go down).

Phase 4

Finally the mask was sent back for post measurements on AIMS™. The post CDU results showed an improvement of 70% in range and 77% in 3S. Note that the control cells have been excluded from the statistics. Figure 7 shows the Post CDU map.



CDU data for corrected area
Control cells have been excluded

	Pre CD (Programmed) nm	Post CD nm	Improvement
Min	65.43	64.07	
Max	70.39	65.53	
Average	68.12	64.88	
Range	4.97	1.47	*70%*
3S	3.98	0.91	*77%*

Figure 7

Discussion

For a mask shop that wants to provide its customers with an optimal CDU mask at a quick delivery time, being able to close the loop between CDU measurment, CDU improvement and CDU verification is critical. In this experiment we made a first feasibility study to take a mask with programmed CD variations and normalize it to a very flat CDU based on AIMS™ CDU data only, without wafer print. The range of CD non uniformity which we corrected was 5nm on mask and the resolution of the correction was equivalent to <0.25nm step. In terms of % deviation we had a Pre CD range of 7% (4.97nm range over 68nm average) and corrected the Post CD range to 2.2% (1.47nm over 65nm).These results compare quite well with CDU improvements that have been achieved on printed wafer using wafer CD SEM or OCD [5]. These results show that CD measurements by the AIMS™ CD-map function are well suited to measure wafer level CDU correctly and serve as an input for CDC correction. An advantage of this method is that it can be done even after pelliclization on both tools as the CDC101 and AIMS™45–193i can process and measure through pellicle.

Process flow in the mask shop

We propose to introduce the CDC process after pelliclizing and final inspection. Figure 8 describes a simple process flow in the mask shop utilizing an AIMS™45-193i and CDC101 after the post pell inspection step.

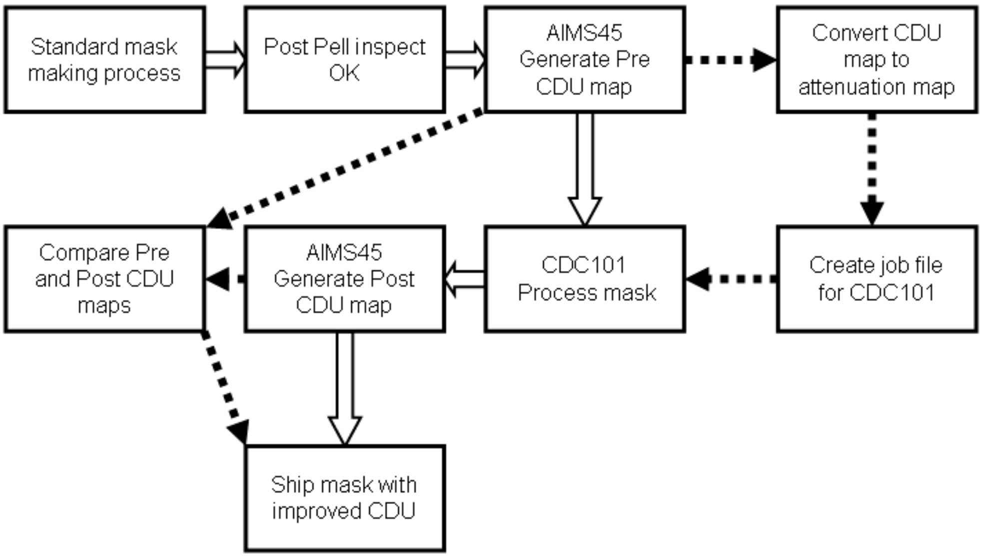


Figure 8

Turn Around Time (TAT)

Assuming the mask shop has AIMS™45-193i and a CDC101 tool the TAT would be the sum of two AIMS™45-193i measurements of 3 fields plus one TAT of the CDC.

A typical total Movement and Measurment (MAM) time of AIMS™45-193i using the CD-map plug in CD measurment mode has been about 60 minutes for 130 points in this study. Assuming 3 repeats (equivalent of 3 fields) this would take 3 hours per one CDU map measured by AIMS™.

The CDC101 TAT depends on the average attenuation applied (the more attenuation the more pixels, the more pixels the longer the process time). A typical 65nm mask with typical current CDU's requires 2.0% average attenuation and takes 5 hours for full active area of 100X100 mm processing.

If we add 30 min for transporting the mask from tool to tool including data processing and preparation of job files the total TAT is about 12 hours in this feasibility study. .

Summary

In this first experiment of combining AIMS™45–193i as a CDU measurment tool with CDC101 as a CDU improvement tool we managed to take a programmed CD mask with a relatively large CD variation and improve the CDU by 70%..

The CDC process allows itself for CDU improvement with a resolution of 0.1nm if reliable CD data is provided. AIMS™45-193i can provide CDU data with a repeatability of < 0.25 - 0.5nm at wafer level. At the current stage more repeat measurements improve the reliability of the data.

CONCLUSIONS

1. We have proved feasibility to correct CDU of the mask by closing the loop in the mask shop through aerial imaging and the CDC process. AIMS™ is a suitable tool for providing CD data for CDC101.
2. With current detection ability of AIMS™45-193i the correction resolution is ~0.5nm.
3. Further improvements of CD repeatability of AIMS™45-193i will allow correction to within 0.1nm on wafer CD.
4. Combing CDC101 and AIMS™ has been demonstrated to be a powerful and promising method for CDU correction in the mask shop.

FUTURE DEVELOPMENT

We intend to repeat this experiment on a real product layer mask and print it on wafer in order to confirm the feasibility of this closed loop process in a real production cycle.

The process should be further verified with different illumination conditions and different features.

REFERENCES

AIMS™ is a trademark of Carl Zeiss. CDC101 is a trademark of Pixer Technology.

Contact author Guy Ben-Zvi guy@pixertech.com

1. Zait et al. CD Variations Correction by Local Transmission Control of Photomasks Done with a Novel Laser based Process. ML 6152-76 SPIE Microlithography 2006

2. Zait et al. Irradiation Resistance of Intravolume Shading Elements embedded in Photomasks used for CD Uniformity Control by Local Intra-field Transmission Attenuation. PMJ 2006 6283-11

3. Morikawa et al. In-field CD uniformity control by altering transmission distribution of the photomask, using Ultra fast pulsed laser technology. PMJ 2006 6283-29

4. Introduction to Mask and Wafer Intrafield Critical Dimension Control (CDC) using Ultrafast Laser. SEMICON Japan 2006

5. Pforr et al. Performance comparison of techniques for intra-field CD control improvement. BACUS 2007

6. R.A. Budd et al. Development and Application of a new tool for lithographic mask evaluation, the stepper equivalent Aerial Image Measurement System, AIMS IBM J. Res. Develop. Vol. 41 No. 1,2 January / March 1997

7. Scherübl et al Programmed Defects Study on masks for 45nm Immersion Lithography using the novel AIMS™45-193i, EMCL 2007.

8. Poortinga, et al, “Improved prediction of Across Chip Linewidth Variation (ACLV) with photomask aerial image CD metrology”, Proc. SPIE Vol. 6349, *Photomask Technology*, 2006.

9. Poortinga et al. Investigation of Hyper-NA Scanner Emulation for Photomask CDU Performance EMCL 2007.