CD Measurement of Angled Lines on High-End Masks and its Calibration Method

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ABSTRACT

Recently, in Critical Dimension (CD) measurement on high-end masks, Optical Proximity Correction (OPC) pattern measurement is on increase and it has become important to measure angled lines.

In CD searching on a CAD layout viewer, the exact CD values can be detected for the OPC patterns because they consist of a lot of rectangles. While, the CD values for angled lines have not been detected in it.

Meanwhile the mask Critical Dimension Scanning Electron Microscope (CD-SEM) can measure angled lines, but measurement accuracy cannot be verified because there is no reference standard sample available for calibration of the CD values.

In this study,

(1) We made the prototype of a standard sample for CD measurement with 0 degree and 45 degree angled lines by using VLSI Standards Inc. Nano Lattice Standard. The shape is the same as 6025 mask.

(2) We measured CDs of angled lines of the above sample using Holon EMU-260 and examined the calibration method.

(3) We are going to discuss the CD marking method on a CAD layout viewer in order to automate measurement of angled lines in near future.

Keywords: CD-SEM, mask, CAD, design data, OPC, angled pattern, calibration, standard, lattice

1. INTRODUCTION

CD measurement for high-end masks requires the necessity of measuring angled lines and its calibration method. We reported on the calibration method (for direction 0 and 90 degree) for the EMU series using the JQA Micro Scale in the previous symposium (Ref.1). Our report described here refers to the outcome of study concerning the calibration method for the 45nm Technology node and after.

2. DIFFICULTIES IN MEASURING OF ANGLED LINES

It is found there are three issues to be resolved for measurement of angled lines.

- Accuracy for the SEM imaging and its reliability (CD-SEM performance)
- Accuracy for the mask patterns and its reliability
- No standard sample available (which includes the traceability for NIST/JQA)

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1. Accuracy for the SEM imaging and its reliability (CD-SEM performance)
   Beam deflection system we use for measurement on the CD-SEM (Holon EMU-260) is of electrostatic deflection type, enabling it to perform the same level of deflection control as the EB writer. It additionally control the field of view less than 0.2% to make accurate pattern matching using the CAD-LINK system.

2. Accuracy for the mask patterns and its reliability

   When we discuss accuracy and its reliability of patterns formed on the mask for CD measurement, it is necessary for us to consider the potential error it has on the EB writer. Current major tools are the vector scan beam (VSB) system which generally writes the angled lines with the rectangular beam. In fact, they are consisting of a large number of small rectangles in the data of EB writer and designed stepwise at the angled line edges. Though the size of staircase depends on the performance of EB writer and its writing conditions, however, we need to measure the patterns with which the edge roughness clearly exists. We also need to consider the data defect which are generated when the CAD data be converted into VSB fracturing as well as the overlay accuracy with an EB writer.

3. No standard sample available (which includes the traceability for NIST/JQA)

   We require to take note of calibrating the real mask patterns, as it contains some critical issues of the error. We as a CD-SEM supplier have made the prototype of mask pattern-independent, standard sample for study to meet the international standard.

   Design & production of the Holon Standard Mask for tool adjustment
   Development of the standard sample (0-45 degree) using the Nano Lattice Standard by VLSI Standard Inc.
   Development of the adapter (with 15 degree revolving mechanism) for the standard sample of the JQA Micro Scale

3. PRODUCTION OF HOLON STANDARD MASK

The standard mask was produced for the purpose of basic adjustment for the CD-SEM tool. Pitch dimension (L/S pattern) is the most important for the measurement pattern necessary for the CD-SEM adjustment. Thus, alignment of the patterns and dimensions has been schemed so that we can verify full adjustment for the linearity and angle dependence for the pitch dimension. We have also designed for the layout of chips considering the possibility of adjusting the stage constant. (Fig. 1)

Parameters we have urged the mask supplier for production of the Holon Standard Mask are guarantee of accuracy for the pitch dimension and linearity. We requested them to produce it on the process that the edge roughness is smaller than accuracy for the pattern dimension (ratio of line/space in design: 1 to 1)

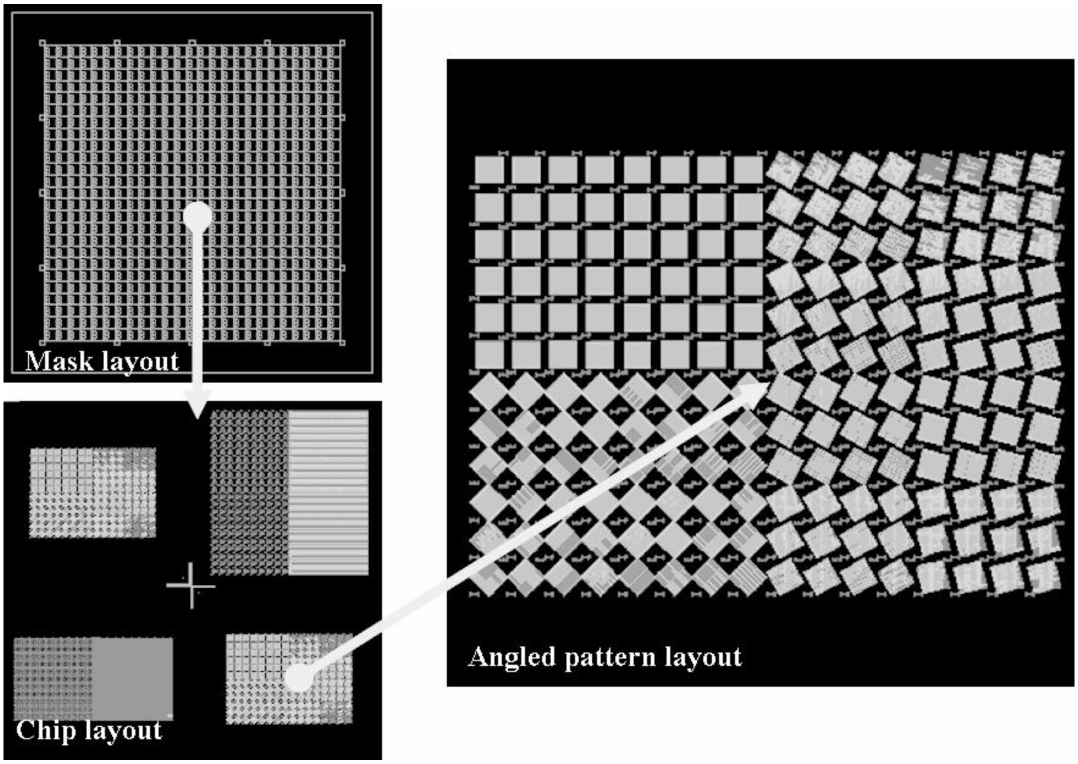


Fig.1 HOLON Standard mask pattern layout

4. PROTOTYPE OF THE STANDARD SAMPLE (0 DEGREE/45 DEGREE-ANGLE) BY VLSI STANDARD INC.

Nano Lattice Standard by VLSI Standard Inc. is the NIST traceable, standard sample for the 100nm node pitch dimension. It enabled calibration by aligning the standard sample with 2 chips, to direction of 0 and 45 degree, which are embedded in the adapter of 6025 mask size as shown in Fig.2. Calibration for direction to 90-135 degree was performed by rotating the sample to 90 degree for transfer.

Pattern angle	0	45	90	135
Measurement value (nm)	400.14	400.98	400.29	400.35

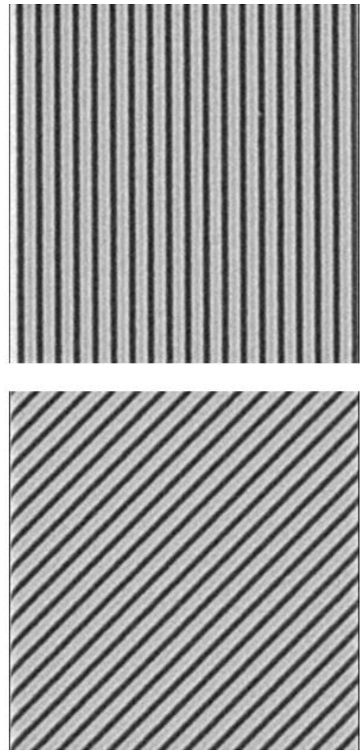


Fig.2 NanoLattice Standard 0-45˚sample (VLSI Standard Inc.)

5. DEVELOPMENT OF THE ADAPTER (WITH EVERY 15 DEGREE REVOLVING MECHANISM) FOR THE STANDARD SAMPLE OF JQA MICRO SCALE

JQA Micro Scale is the standard samples for pitch dimension 240nm (239.9nm).
We required to develop the adopter in use for 6025 mask size, as JQA supplied us a small fragment (for the cross section SEM). The stage for rotating the sample is not installed on the EMU series. So we made the prototype of adapter with every 15 degree revolving mechanism to execute calibration of a certain angle and verify its accuracy.

6. EXPERIMENT 1. MEASUREMENT OF HOLON STANDARD MASK

Firstly, the Experiment conditions are set forth in the Table1.
We measured the total 75 points i.e. 3 points per chip times 25 chips in the central area of mask considering local roughness of the patterns measured. All mean values for measurement of 75 points are adopted as a mean one to each of the CD values (pitch dimension). Main purpose of our test plan was to verify the performance of the tool. We examined the pattern angle-dependent, measurement error by limiting the angled patterns in use to 0-15-30-45-60-90 degree and by rotating the mask to 0-90-180-270 degree for other angles.

Table 1. CD-SEM Measurement conditions

HOLON Standards Mask Version. 01

- **Acceleration voltage : 1500V**
- **Beam current : 7.5pA**
- **Magnification (FOV) : 50kX (3um)**
- **Sample type : COG binary**
- **Measuring point : 75 points**
- **CD design: 200, 400, 600, 800nm L/S**
- **Angle : 0˚, 15˚, 30˚, 45˚, 60˚, 75˚, 90˚**
- **Mask rotation : 0˚, 90˚, 180˚, 270˚**

7. MEASUREMENT RESULT FOR EXPERIMENT 1 AND ITS CONSIDERATION

The result of pitch measurement for Holon Standard Mask (prototype) is listed in the Table2 and in Fig.3a & Fig.3b. Pattern dimensions for measurement are 400nm(200nm LS), 600nm(300nm LS), (800nm(400nm LS), 1200nm(600nm LS)and 1600nm(800nm LS). Measurement result indicates that variation of the measured vales depend on local roughness of every angled patterns formed on the mask. Reasons to support it are described below in case that the mask plate be rotated to 0-90-180-270 degree.

(1) Difference of dimensions measured is less than 0.7nm for each of the same design Mean value for the patterns with 0-15-30-45-75-90 degree is less than 0.3nm.
(2) CD variation of every angled patterns shows the same trend in conjunction with the revolving angle of the plate.

The amount of CD variation for measurement of every angled patterns was larger than measurement error it has on the tool. As a result of it, we could not ensure the tool-specific measurement error which is considered less than 0.3nm. Though the difference of CD values for 0-15-30-45-60-75-90 degree patterns is larger than we expected, it is thought that the mask supplier is not ready for optimization of the processes because we made the first prototype of it. As the CD values become large, however, variation for every angled pitch dimensions gets increased. This phenomenon is considered attribution to the conversion from the CAD data into the imaging format and the processing of the mask writer used. When we consider the evaluation method for the angled lines after the Experiment, it has turned out that our verification for CD measurement requires to consider the specific issues such as the tool difference of the mask writer and supplier difference including conversion of the writing data.

Table 2. HOLON Standard mask angled pattern measurement

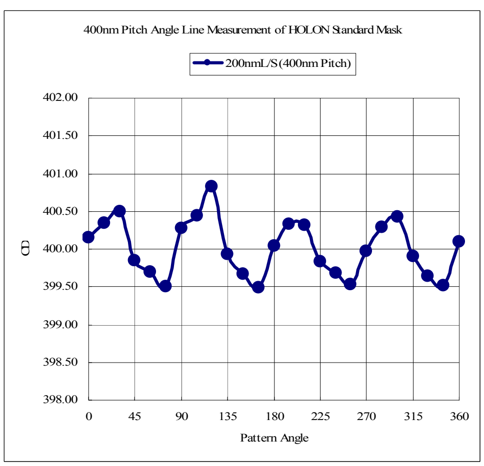
Mask rotation	200nmL/S (400nm Pitch) tilt angle							
	0	15	30	45	60	75	90	Average
0 degree	400.15	400.33	400.47	399.84	399.70	399.50	400.04	400.01
90 degree	400.28	400.47	400.81	399.93	399.64	399.48	400.04	400.09
180 degree	400.03	400.32	400.30	399.82	399.64	399.54	400.09	399.96
270 degree	399.98	400.30	400.38	399.88	399.62	399.50	400.09	399.96
Mean	400.11	400.36	400.49	399.87	399.65	399.51	400.07	400.01
Range	0.30	0.17	0.51	0.11	0.08	0.06	0.05	0.13

Mask rotation	400nmL/S (800nm Pitch) tilt angle							
	0	15	30	45	60	75	90	Average
0 degree	800.04	799.61	800.31	799.84	799.55	801.39	799.83	800.08
90 degree	800.10	799.74	800.43	800.00	799.49	801.43	799.85	800.15
180 degree	799.77	799.48	800.17	799.84	799.58	801.51	800.08	800.06
270 degree	799.70	799.48	800.38	800.00	799.39	801.48	800.12	800.08
Mean	799.90	799.58	800.32	799.92	799.50	801.45	799.97	800.09
Range	0.40	0.26	0.26	0.16	0.19	0.12	0.28	0.09

Mask rotation	600nmL/S (1200nm Pitch) tilt angle							
	0	15	30	45	60	75	90	Average
0 degree	1200.47	1198.67	1200.51	1201.27	1200.83	1200.94	1198.99	1200.24
90 degree	1200.47	1198.96	1200.56	1201.64	1200.92	1201.06	1198.81	1200.35
180 degree	1200.05	1198.53	1200.24	1201.24	1200.38	1201.11	1199.31	1200.12
270 degree	1200.02	1198.47	1200.31	1201.40	1200.64	1201.16	1199.26	1200.18
Mean	1200.25	1198.66	1200.41	1201.39	1200.69	1201.07	1199.10	1200.22
Range	0.45	0.49	0.32	0.40	0.55	0.22	0.50	0.22

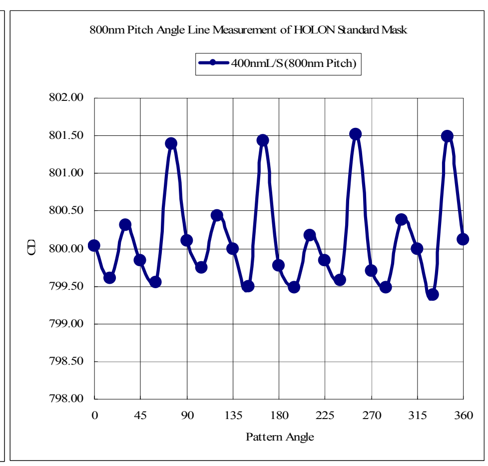
Mask rotation	800nmL/S (1600nm Pitch) tilt angle							
	0	15	30	45	60	75	90	Average
0 degree	1599.76	1599.97	1599.46	1600.24	1601.07	1600.68	1598.36	1599.93
90 degree	1600.09	1600.33	1599.96	1600.63	1601.17	1600.64	1598.28	1600.16
180 degree	1599.58	1599.76	1599.37	1600.07	1600.87	1600.82	1598.72	1599.88
270 degree	1599.38	1599.71	1599.54	1600.29	1600.87	1600.80	1598.59	1599.88
Mean	1599.70	1599.94	1599.58	1600.31	1600.99	1600.73	1598.49	1599.96
Range	0.71	0.62	0.59	0.57	0.30	0.18	0.43	0.28

200nm L/S Pattern



Y scale = 0.5nm/unit

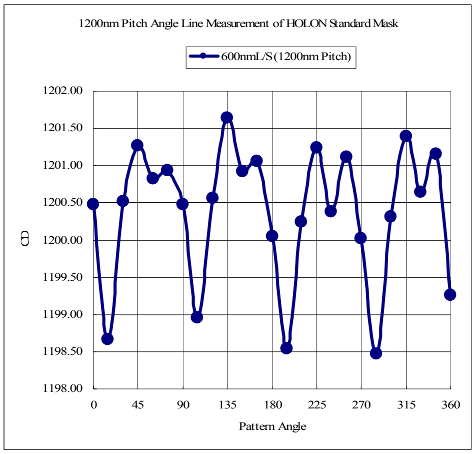
400nm L/S Pattern



Y scale = 0.5nm/unit

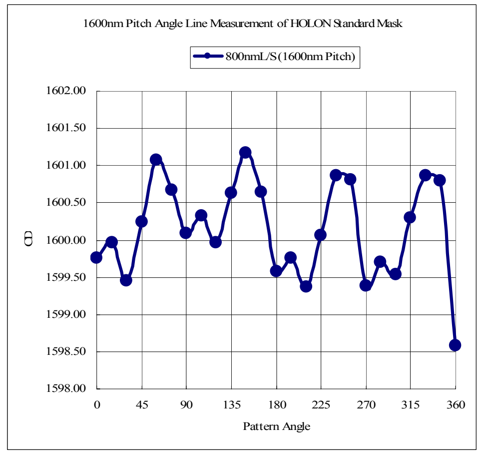
Fig.3a HOLON Standard mask angled pattern measurement

600nm L/S Pattern



Y scale = 0.5nm/unit

800nm L/S Pattern

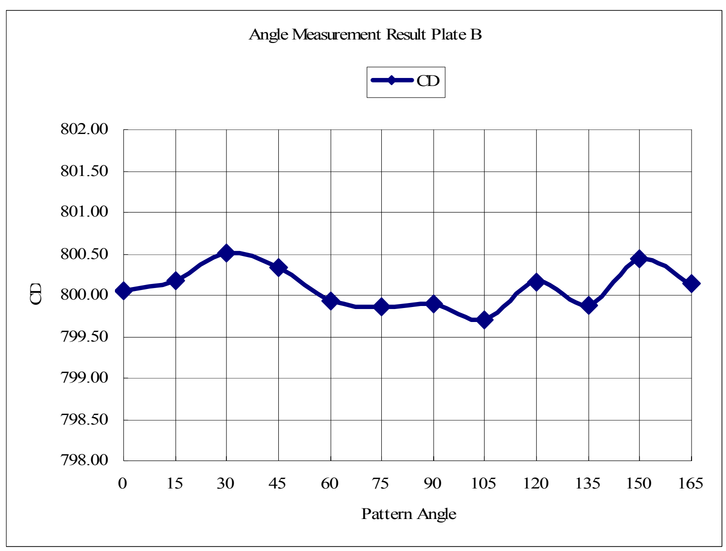


Y scale = 0.5nm/unit

Fig.3b HOLON Standard mask angled pattern measurement

Fig.4 shows the user's mask measurement result for the angled patterns formed using a different supplier of mask writer from the Holon standard mask we prototyped. We could not clearly separate between CD-SEM-specific measurement error and patterning error of the mask even in this measurement.

Pattern Angle	CD
0	800.05
15	800.17
30	800.50
45	800.33
60	799.93
75	799.85
90	799.89
105	799.71
120	800.15
135	799.88
150	800.44
165	800.15
Average	800.09
Range	0.80



Y scale = 0.5nm/unit

Fig.4 Angled pattern measurement for the user's mask plate

8. EXPERIMENT 2: MEASUREMENT USING JQA MICRO SCALE WITH INCORPORATING 15 DEGREE REVOLVING MECHANISM

We measured the standard sample of JQA using the adapter of our development with 15 degree revolving mechanism. Measurement was made for 50 points per angle at 15 degree intervals. Since the JQA standard sample we used for the Experiment is two-axis type (X/Y) and the mean values for X and Y-axis are finally adopted by measuring each of two standard samples separately, the total measurement comes to 500 points. The experiment conditions are listed in the Table 3.

Table 3. CD-SEM Measurement conditions

JQA Angle measurement

- **Acceleration voltage : 1500V**
- **Beam current : 7.5pA**
- **Magnification (FOV) : 75kX (2um)**
- **Standard CD : 239.9nm**
- **Measuring point : 250 points *2(XY)**
- **Measuring angle : 0-360°/ @15°**

9. RESULT OF EXPERIMENT 2 AND ITS CONSIDERATION

The measurement result for the JQA with every 15 degree rotated was shown in Fig.5. As indicated in the result of Experiment, accuracy measurement was made for a pitch dimension of 240nm(239.9nm) at the tool adjustable angle of 0-90-180 degree for the SEM imaging and however, the tendency has been to generate the measurement error of sine curve-like which is the CD-SEM-specific, for measurement of the other angled patterns. This is considered contribution to distortion of the deflection system. The amount of these errors, +/-0.3nm (+/-0.125%) is not used for calibration. It is believed therefore, that the appropriate way is to develop the software for correction and improve its accuracy to meet the measurement specifications for 45nm technology node and after. We could verify finding out the root cause of the CD-SEM-specific measurement error by rotating the JQA Standard Sample for measurement, which was not accessed in the measurement of angled patterns formed on the mask.

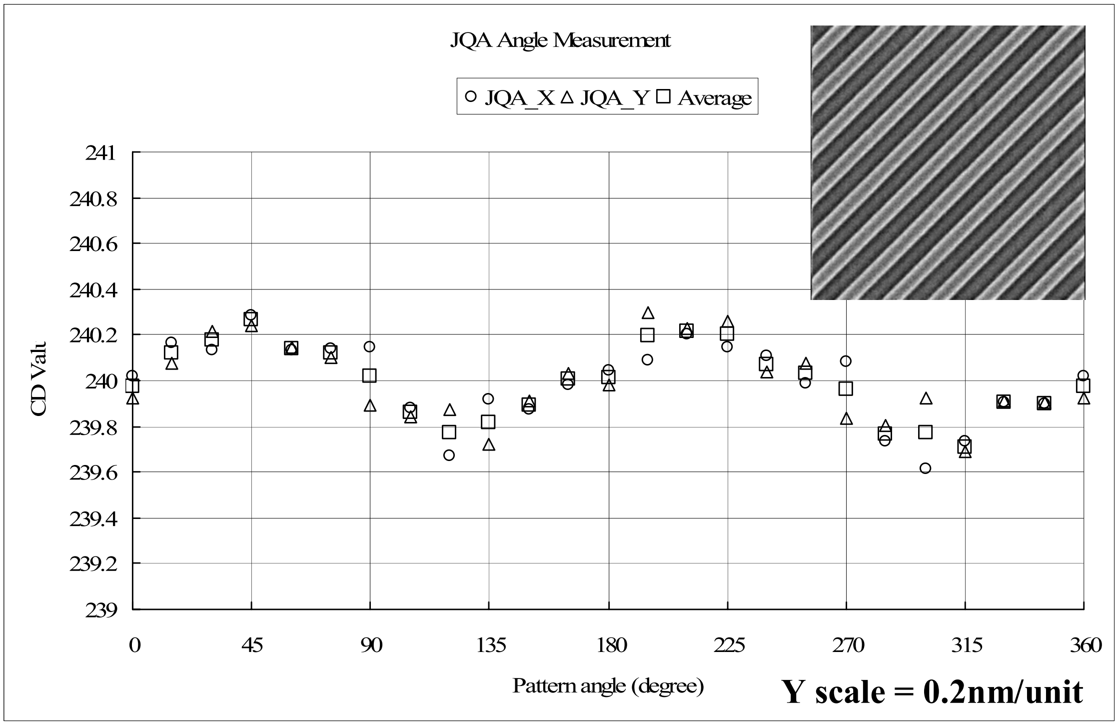


Fig.5 JQA angle measurement result by HOLON CD-SEM

10. SUMMARY

We studied the reliability of measuring the angled lines through the process to develop the CD measurement and its calibration method.

- For measurement error of the angled lines there interlaces the CD-SEM tool-specific measurement error and patterning error on the mask. It is found out that the measurement method to simply use the mask patterning is not suitable for calibration of the angled lines.
  As seen in the result of Experiment, the reliability of angled lines tends to be affected by the performance of the mask writer and the cause of error when the writing format be converted. In case that we conduct calibration of the angled lines on the masks produced using the mask writers by some different suppliers and those of the different models, therefore, it is necessary to understand that the CD reliability is unequal.

- We could detect the CD-SEM tool-specific error for measurement of angled lines by rotating the standard sample for measurement. Our Experiment ensures the measurement error of +/-0.125% to 0 degree measurement. Since the maximum value for measurement error demonstrates the tendency of sine curve with approximately 45 degree atop, we assume this is the error in conjunction with an electrostatic deflector and are pursuing the root cause presently.

- We have prototyped the Nano Lattice Standard by VLSI Standards Inc. as a standard sample for 0 and 45 degree and ascertained the effectiveness of it for real calibration

11. FUTURE WORK

We have studied CD measurement and its calibration method for the angled lines and herewith list the items for upcoming necessary development and improvement briefly.

1. Items for development and improvement of the CD-SEM tool
   - To develop the calibration table of measurement angles for the EMU tools and its software for correction

2. Measures to verify the reliability for the angled patterning
   - To verify comparison (via CAD-LINK) between the writing data and mask patterning
   - To enable obliquely-directed CD marking on the CAD data and display of the CD values

3. Items of improvement for the international standard samples
   - Increase of the digit number displayed for measurement values calibrated
   - Delivery time and price

12. ACKNOWLEDGEMENT

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13. REFERENCE

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