Assurance of CD for 45 nm Half-Pitch with Immersion Microscope

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ABSTRACT

A new calibration method for critical dimension (CD) linearity improvement with an immersion microscope is proposed. Correlation tables of an edge position against CD of the clear pattern and CD of the dark pattern are obtained experimentally. The detected edge position is calibrated with the correction tables. Distance between the calibrated edge positions is output as CD. The experiment result indicates the calibration method improves CD linearity of an immersion microscope. CD repeatability with the calibration method using an immersion microscope is found to be sufficient for 45nm HP masks. As a result, an immersion microscope with our calibration method is available for CD measurement of 45 nm HP masks.

Keywords: Calibration, Critical dimension, Immersion, Linearity, Metrology, Optical microscope

1. INTRODUCTION

For photomask critical dimension (CD) measurement, an optical microscope has been commonly used. The most significant advantage of an optical microscope is that the CD repeatability is excellent. Furthermore, in an optical microscope, the light is transmitted through a photomask just as it is in a wafer aligner. Therefore, CD of an optical microscope is consistent with CD of the wafer image even if the cross-sectional profile on a photomask is varied [1-3].

On the other hand, the most significant disadvantage of an optical microscope is that the resolution is insufficient. Table 1 shows optical parameters of optical microscopes. Although the resolution of an immersion microscope is superior to that of a conventional 'dry' microscope, the CD linearity of an immersion microscope cannot be maintained below 0.26 μm. This means that CD measurement with an immersion microscope is available for a main pattern of 65 nm half-pitch (HP), but it is unavailable for a sub-resolution assist feature (SRAF), and it is also unavailable for 45 nm HP.

In this paper, a new calibration method for CD linearity improvement using an immersion microscope is proposed. We demonstrated that our method with an immersion microscope is available for CD measurement of 45 nm HP masks.

Table 1. Optical parameters of immersion and dry microscopes

	λ (wavelength) [nm]	$NA_{objective}$	$NA_{condenser}$
Immersion microscope	248	1.25	0.55
Dry microscope	248	0.9	0.55

2. METHODOLOGY

2.1 Problem of CD with an immersion microscope

Schematic optical setup of an immersion microscope is shown in Fig. 1. Water is inserted between the objective lens and photomask, enabling the numerical aperture (NA) of more than 1.

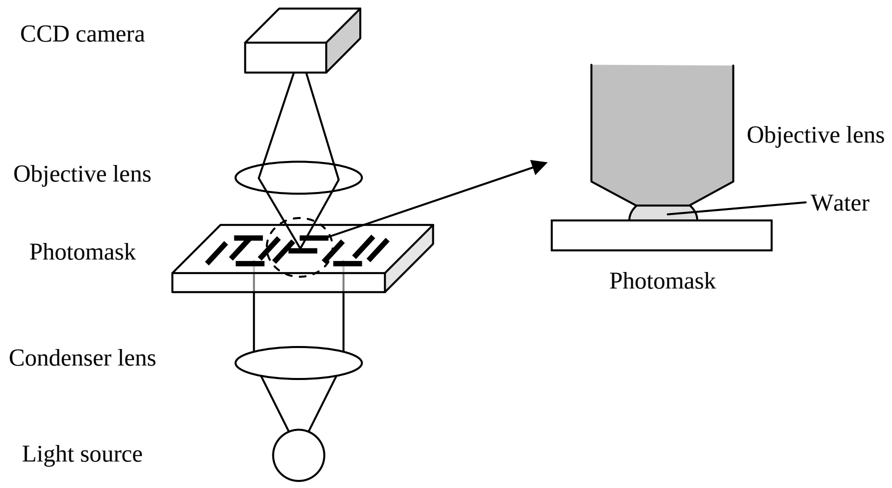

Fig. 1 Schematic optical setup of an immersion microscope

An image of a measurement pattern is obtained with a CCD camera. An intensity profile of the pattern is extracted from the image. A threshold is determined as a relative ratio between the maximum and the minimum intensity: for example, 50%. The edge position is detected with the threshold on the intensity profile. Distance between the detected edge positions is output as CD (Fig. 2).

If a pattern is resolved sufficiently, the maximum intensity reaches the intensity at the clear area. The detected edge position corresponds to the actual edge position with a threshold and the CD linearity can be maintained (Fig. 3(a)). If a pattern is resolved insufficiently, the maximum intensity does not reach the intensity at the clear area, and the detected edge position does not correspond to the actual edge position with the threshold. Then, there is deviation between the actual and the detected edge position, and the CD linearity cannot be maintained (Fig 3(b)).

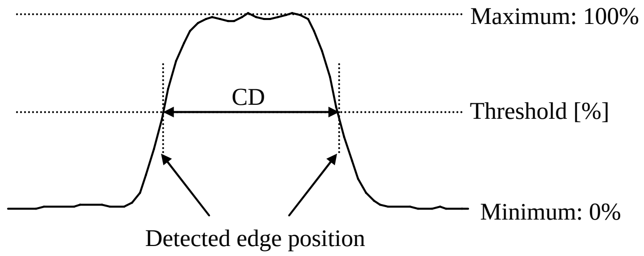

Fig. 2 Intensity profile of a pattern and procedure for the CD

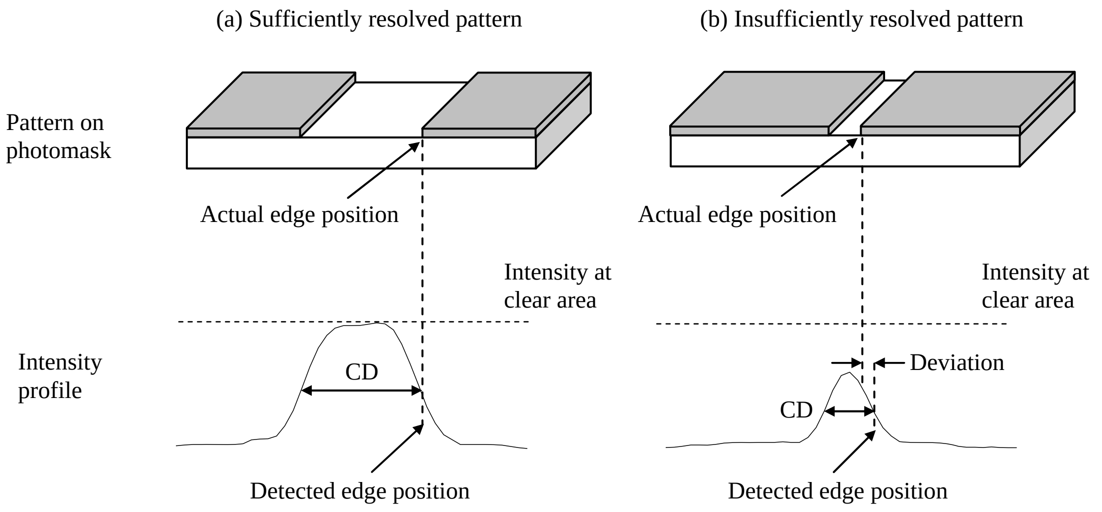

Fig. 3 The actual edge position and the detected edge position of (a) sufficiently resolved pattern and (b) insufficiently resolved pattern

2.2 Factors concerning deviation from an actual edge position

Factors concerning deviation between the actual and the detected edge positions are considered. We think that the CD of the clear pattern, *a* in Fig. 4, is the most important factor concerning the deviation. CD of the dark pattern, *b* in Fig. 4, is the second most important factor concerning the deviation. When *a* and *b* are smaller, the deviation must be larger.

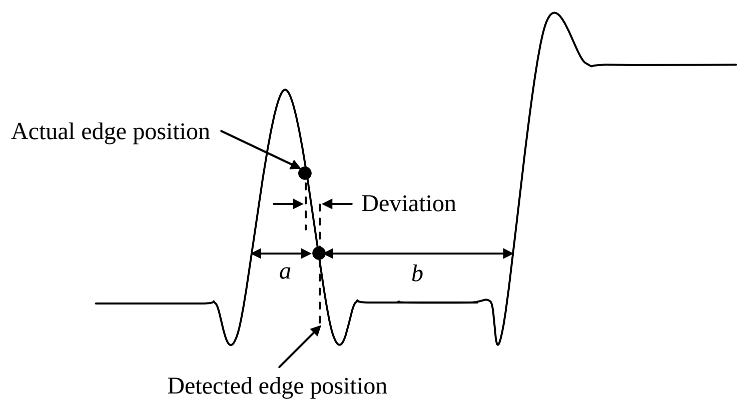

Fig. 4 Factors concerning the deviation between the actual and the detected edge positions
a indicates CD of the clear pattern, and *b* indicates CD of the dark pattern.

2.3 Calibration method for CD linearity improvement

A detected edge position is calibrated with the neighboring CDs, *a* and *b* in Fig. 4. The procedure of our calibration method consists of the following 4 steps, and is shown in Fig. 5.

1) Deviations between the actual and the detected edge positions on a standard mask are measured experimentally. The standard mask has isolated space patterns and isolated line patterns whose sizes are varied within 0.1 – 0.5 μm. The nominal CDs of the patterns are obtained: for example, wafer images of the patterns are obtained with a wafer image microscope and CDs of the patterns are calculated with the wafer images using simulator [1, 2]. CDs of another microscope, a scanned electron microscope (SEM) or an atomic force microscope (AFM), are also available as substitutes for the nominal CDs. The nominal CDs are referred to as *A* for the clear pattern and *B* for the dark pattern. Then, the patterns are measured with an immersion microscope. The measured CDs are referred to as *a* for the clear pattern and *b* for the dark pattern. Deviation of an edge position on a clear pattern is referred to as Δa, and that on a dark pattern is referred to as Δb. The deviations are obtained as

$$\Delta a = (A - a)/2$$
$$\Delta b = (B - b)/2$$

2) Correlation tables of an edge position against *a* and *b* are obtained. Δa and Δb are plotted against *a* or *b*. Fitting the plots, correlation tables of an edge position, $f(a)$ and $g(b)$, are obtained.

3) Detected edges are calibrated. A deviation of an edge position caused by *a* is determined with $f(a)$, and that by *b* is determined with $g(b)$. The 'total' deviation is assumed to be $f(a) + g(b)$. Then, a detected edge position is calibrated using $f(a) + g(b)$.

4) Distance between the calibrated edge positions is output as CD.

3. EXPERIMENT

3.1 CD linearity

CD linearity improvement by our calibration method is confirmed experimentally. 0.1 – 0.35 μm isolated-space, isolated-line, center of line/space, edge of line/space, isolated hole, center of hole-array, and edge of hole-array patterns on ArF attenuated phase shift mask (Att. PSM) were prepared (Fig. 6). CDs of the patterns were measured using an immersion microscope with the calibration method, and were measured with no calibration. The threshold used is 50 %. CDs of the patterns were also measured using a SEM. Because the resolution of a SEM is far superior to that of an immersion microscope, CD linearity improvement was confirmed using CD deviations from CDs of SEM. CD deviations of the calibrated CDs were compared with those of the uncalibrated CDs.

Figures 7 and 8 show CD deviations from CD of SEM. Table 2 shows the minimum sizes to maintain the CD linearity. With no calibration, CD linearity cannot be maintained below 0.26 μm. With the calibration method, CD linearity can be maintained until 0.1 μm for isolated space and isolated line patterns, 0.16 μm for line/space patterns, 0.2 μm for hole patterns. This result indicates that our calibration method improves CD linearity of the immersion microscope and CD linearity of an immersion microscope with our calibration method is sufficient for 45 nm HP.

Table 2. The minimum sizes to maintain CD linearity with/without calibration

	Isolated line	Line/space	Hole
Uncalibrated	0.26	0.26	0.26
Calibrated	0.10	0.16	0.20

[μm]

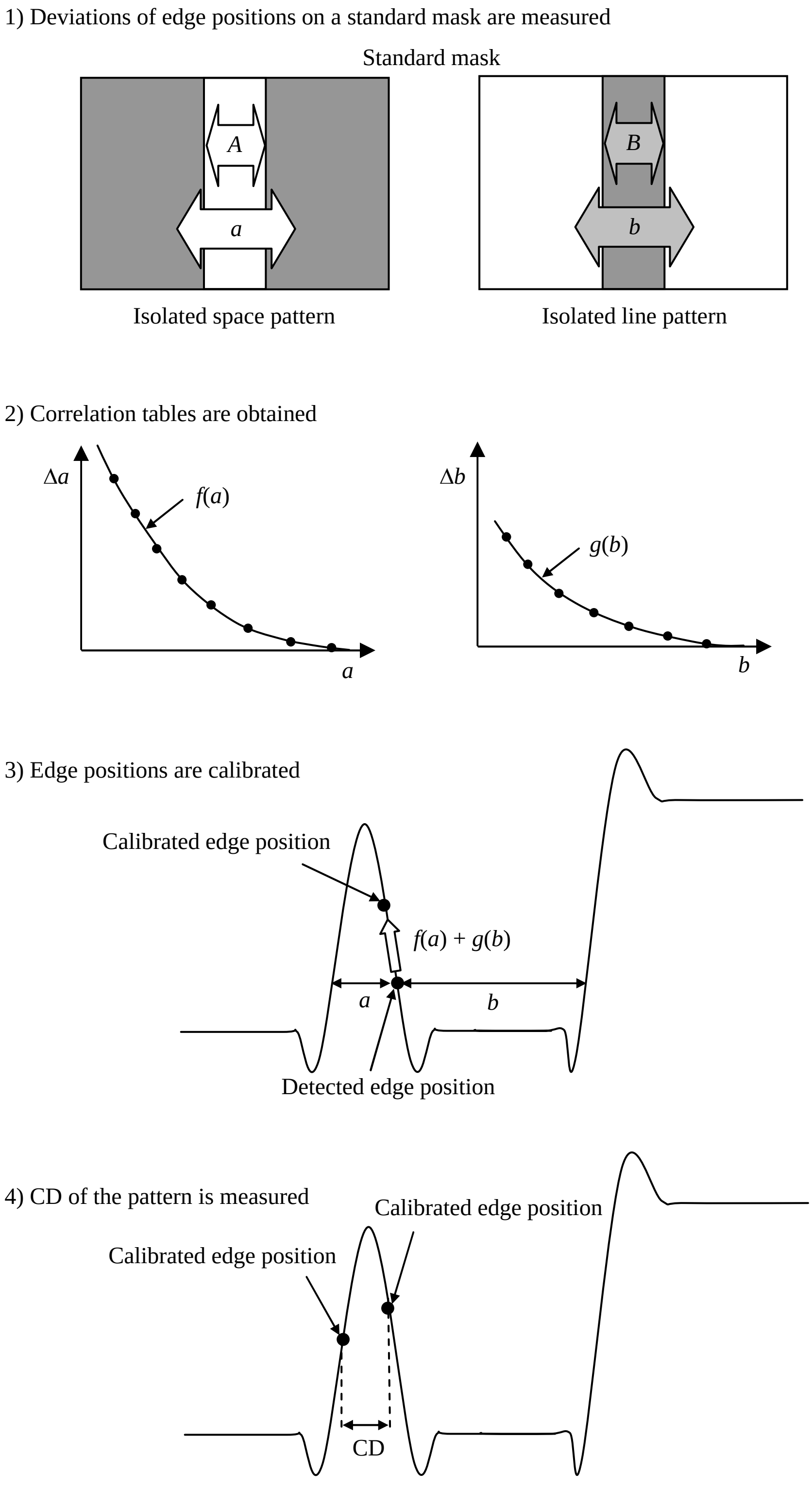

Fig. 5 Procedure to obtain CD with our calibration method

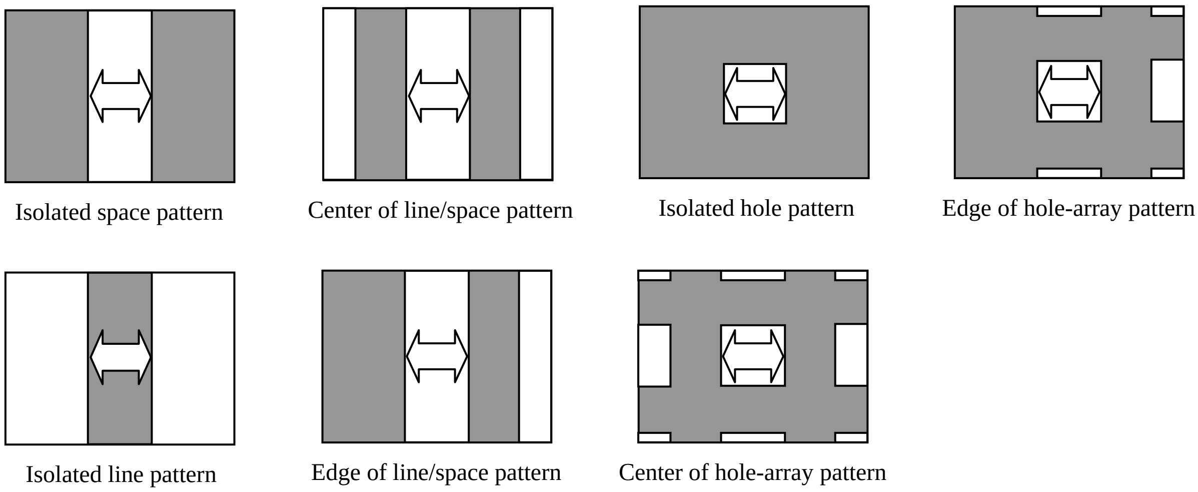

Fig. 6 Measurement patterns on an ArF attenuated phase shift mask (Att. PSM)

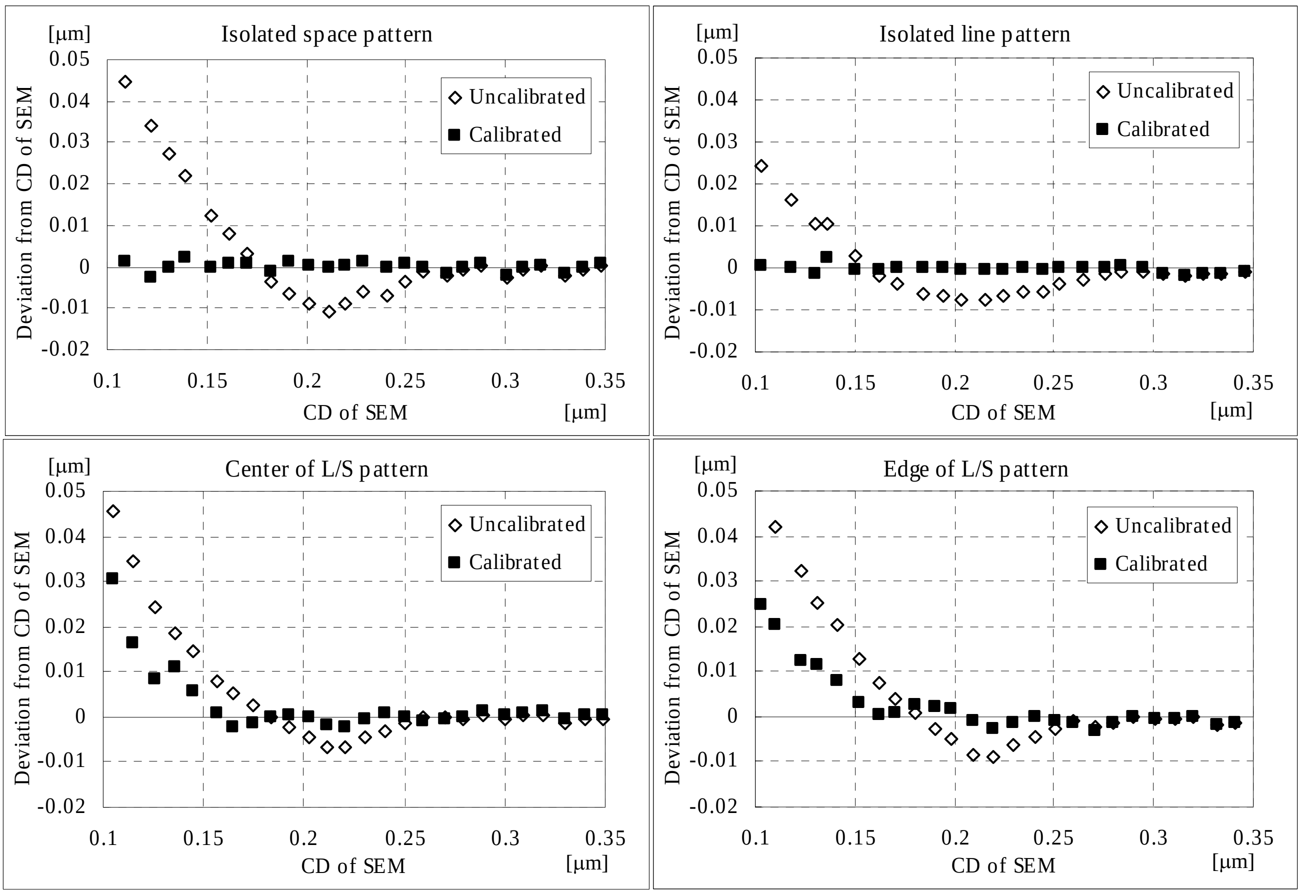

Fig. 7 CD linearity improvement for line patterns on ArF Att. PSM with our calibration method

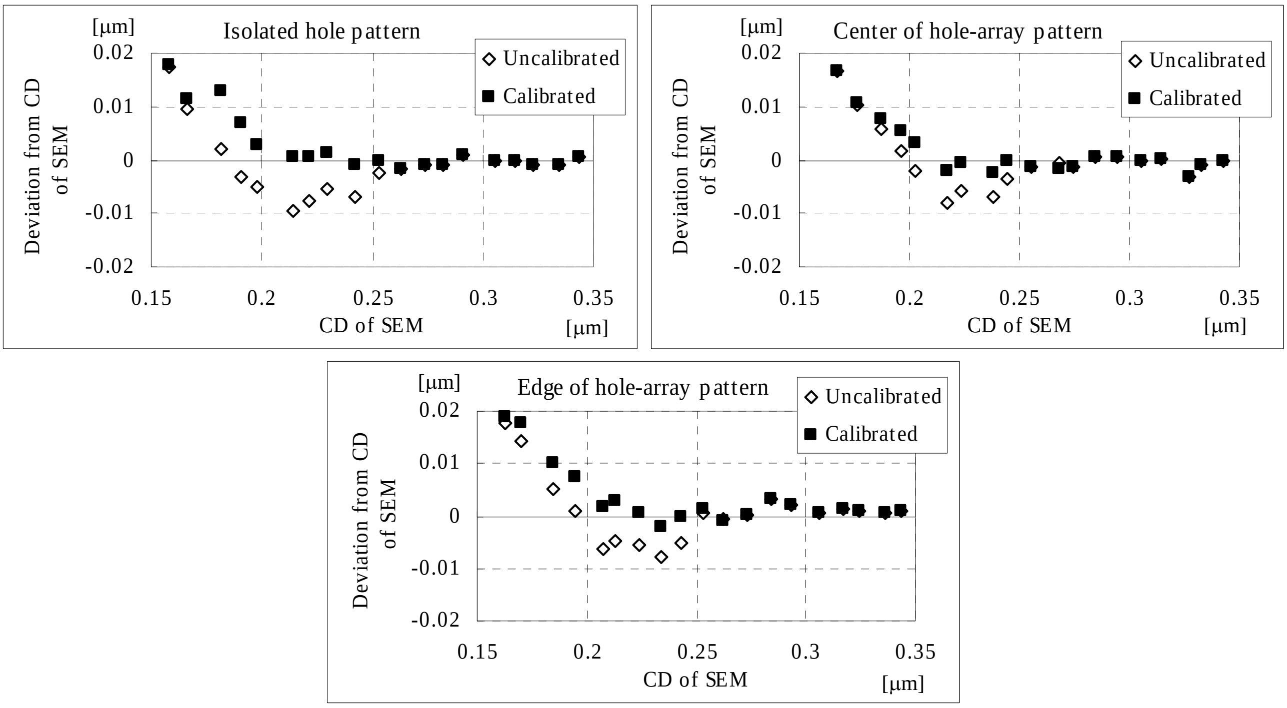

Fig. 8 CD linearity improvement for hole patterns on ArF Att. PSM with our calibration method

3.2 CD repeatability

CD repeatability with the calibration method was evaluated. 0.18 μm isolated space, isolated line, line/space and 0.36 μm hole patterns were assumed as to be the patterns on 45 nm HP masks. Figure 9 shows 20 times static repeatability of the patterns. The 3 sigma values are below 0.5 μm. The required CD repeatability for 45 nm HP masks is 0.7 nm. The CD repeatability with our method is sufficient for CD measurement on 45 nm HP masks.

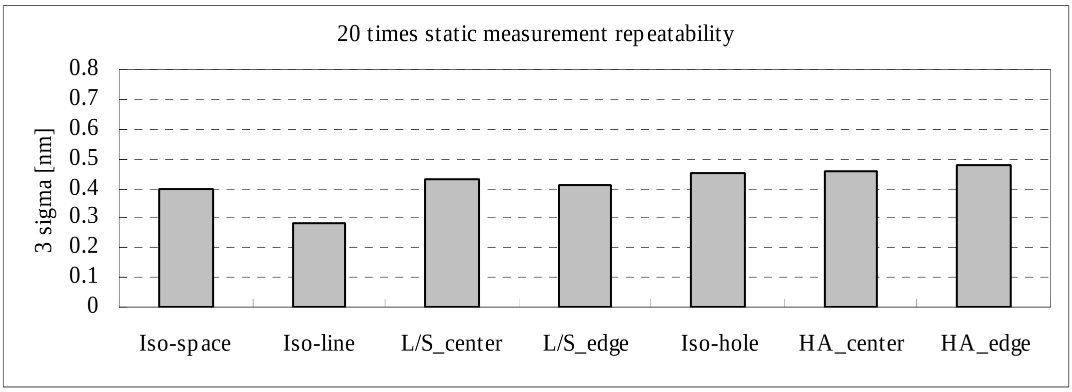

Fig. 9 20 times static measurement repeatability on ArF Att. PSM with our calibration method

4. DISCUSSION

We assumed that deviation of an edge position is $f(a) + g(b)$. This means that the lights from the neighboring clear patterns are assumed as to be incoherent. The coherency illuminated area of diameter (d) is obtained as [4]

$$d = 0.16 \times \lambda / NA_{condenser}$$

In the immersion microscope used, d is 72 nm. If the distance between the neighboring clear patterns is far larger than d, the deviation can be obtained as $f(a) + g(b)$.

In the case of SRAF patterns, the distance to the neighboring main pattern is large enough for it to be regarded as 'isolated'. If the pattern size of SRAF on 45 nm HP is assumed as to be 100 nm, the distance to the neighboring pattern is 260 nm. The neighboring patterns are resolved separately, and then the CD of SRAF can be calibrated correctly.

The minimum pattern sizes with the calibration method using an immersion microscope are 0.1 μm for isolated line patterns, 0.16 μm for line/space patterns, 0.2 μm for hole patterns. If the smaller patterns are measured, the interference effect must be considered in the calibration. Otherwise, some hardware improvement, larger NA for example, will be needed.

5. CONCLUSION

CD linearity improvement by the new calibration method with an immersion microscope is proposed. The experiment result indicates that CD linearity can be maintained until 0.1 μm for isolated line patterns, 0.16 μm for line/space patterns and 0.2 μm for hole patterns with our calibration method. CD repeatability with our calibration method is below 0.5 nm at 3 sigma. The result means that an immersion microscope with our calibration method is available for CD measurement on 45 nm HP masks. The calibration method has no impact on throughput, and therefore throughput using the calibration method is satisfactory for production.

The calibration method is not only for an immersion microscope but also for a dry microscope. We plan to apply the calibration method for a dry microscope. Also, subject for future work is evaluation with device patterns of 45 nm HP.

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