

# CD Metrology by an Immersion Microscope with High NA Condenser Lens for 45 nm Generation Masks

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## ABSTRACT

An immersion microscope with high NA condenser lens is evaluated. The effects of high NA condenser lens are studied by means of simulation and experiment. One effect is CD linearity improvement. We have already reported that our calibration method improves CD linearity of an immersion microscope. The simulation result indicates the high NA condenser lens improves the accuracy of the calibration method. Another effect is CD repeatability. The experimental result demonstrates the high NA condenser lens reduces the peak of intensity profile and improves CD repeatability. As a result, an immersion microscope with high NA condenser lens is available for CD measurement of 45 nm generation masks.

**Keywords:** Critical dimension, Immersion microscope, Linearity, Repeatability

## 1. INTRODUCTION

An optical microscope is a commonly used tool for photomask critical dimension (CD) measurement. The most significant advantage is that the optics is similar to that of a wafer aligner. The light is transmitted through a photomask just like that in a wafer aligner. We investigated this advantage using diffraction theory<sup>1,2</sup>. Two patterns that cross-sectional profiles are different are assumed (Fig. 1). CDs of the two patterns are assumed to be measured with an optical microscope. We calculated the condition such that the CDs are the same and the wafer images of the two patterns are the same. The sidewall width is far smaller than the wavelength, and therefore, the microscope and a wafer aligner cannot resolve the sidewall. Only transmitted light intensity, which means 0<sup>th</sup> order ray intensity, influences the microscope image and the wafer image. Hence, if transmitted light intensities of the two patterns are the same, whole diffraction rays are the same. The numerical aperture (NA) of the microscope is approximately four times larger than that of a wafer aligner. However, because the whole diffraction rays are the same, the microscope images of the two patterns are the same, and the wafer images of the two patterns are the same (Fig. 1). Therefore, if transmitted light intensities are the same, the CDs are the same, and the wafer images are the same. This means that transmitted light intensity is the key factor for the same CDs and the same wafer images, and therefore, optical CD is consistent with the wafer image. This is the most significant advantage of optical CD metrology.

However, optical CD metrology has some problems. The most significant problem is the shortage of resolution. Although an immersion microscope has the highest resolution among the optical CD measurement tools, the CD linearity cannot be maintained until 260 nm. It is insufficient for CD measurement of 45 nm generation photomasks. The other problem is CD repeatability. In the current immersion microscope, CD repeatability on ArF attenuated phase shift mask (att. PSM) is 0.35 nm at 3 sigma for line patterns, and 0.83 nm for hole patterns. According to the ITRS roadmap, the required CD measurement accuracy for 45 nm generation photomasks is 0.68 nm. CD repeatability for hole pattern is insufficient, whereas CD repeatability for line patterns is sufficient.

We evaluated an immersion microscope with high NA condenser lens. We expected there to be two effects of high NA condenser lens, namely, CD linearity improvement and CD repeatability improvement. We evaluated these items by means of simulation and experiment.

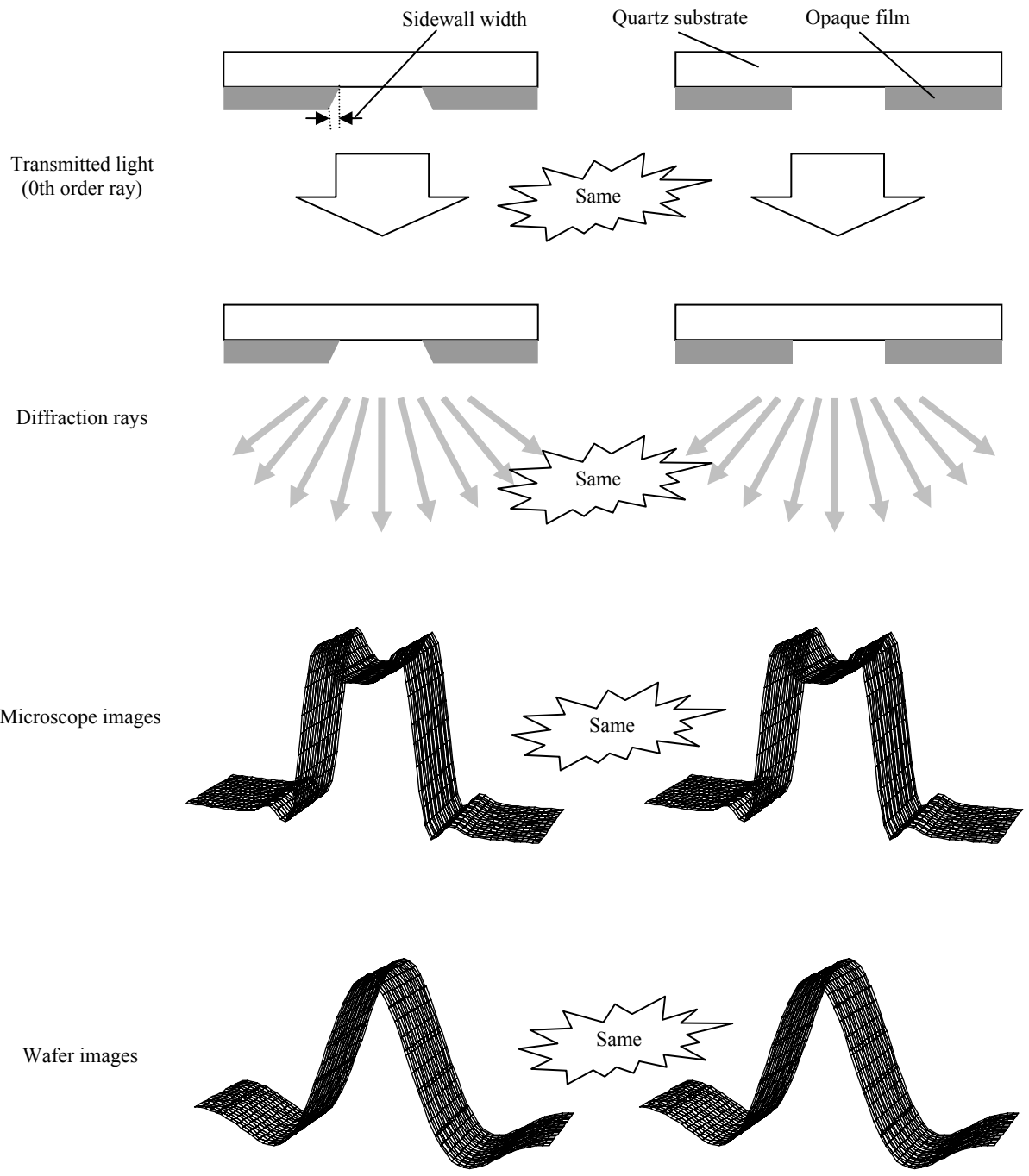


Fig. 1 Schema for the condition such that CDs are the same and the wafer images are the same

## 2. CD LINEARITY IMPROVEMENT

### 2.1 Optical parameters

Table 1 shows optical parameters of a current immersion microscope and an immersion microscope with high NA condenser lens<sup>4</sup>. The condenser NA is enlarged from 0.55 to 0.8. In all other respects, the optics of the high NA microscope is the same as that of the current immersion microscope.

Table 1. Optical parameters of current immersion microscope and immersion microscope with high NA condenser lens

	$\lambda$ (wavelength) [nm]	NA <sub>objective</sub>	NA <sub>condenser</sub>
Current immersion microscope	248	1.25	0.55
Immersion microscope with high NA condenser lens	248	1.25	0.8

### 2.2 Calibration method

We have already reported the CD calibration method for CD linearity improvement<sup>5</sup>. When a pattern is resolved insufficiently in the microscope, the detected edge position is deviated from the actual edge position (Fig. 2). In the calibration method, the deviation is calibrated by

$$f(a) + g(b) \quad (1)$$

$f(a)$  : Deviation by a space pattern

$g(b)$  : Deviation by a line pattern

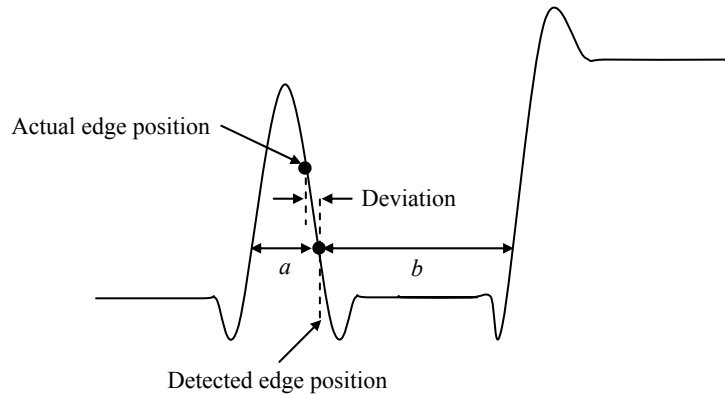


Fig. 2 Deviation of detected and actual edge positions on intensity profile of an optical microscope

$f(a)$  and  $g(b)$  are obtained experimentally on isolated space and isolated line patterns. CD is output as distance of the calibrated edge positions. Table 2 shows CD linearity improvement by the calibration method with the current microscope.

Table 2. CD linearity improvement for current immersion microscope by the calibration method

	Minimum measurement pattern size [nm]	
	NOT calibrated	Calibrated
Isolated line	260	100
Line and space	260	160
Hole	260	200

### 2.3 Simulation

In equation (1), the interference is assumed to be incoherent. This means two lights from neighboring space patterns are incoherent. The coherency illuminated area of diameter ( $d$ ) is obtained as <sup>3</sup>

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

The high NA condenser will reduce the coherency illuminated area of diameter from 72.1 nm to 49.6 nm. When the condenser NA is enlarged, the coherency illuminated area of diameter is reduced and the interference of two lights from neighboring space patterns is so close that it results in incoherence. The accuracy of the calibration method is expected to be improved.

The accuracy of the calibration method was verified with simulation. Line and space patterns, whose pitches are 360 nm and space pattern sizes are 68 nm – 180 nm, are assumed. The images of these patterns are calculated by Fourier transformation using optical parameters of the microscopes. CDs of the space patterns are obtained with the simulated images using the calibration method.

Figure 3 shows deviations of the CDs from the space pattern sizes. With the current microscope, the deviations are 2 nm at the maximum. With the high NA condenser microscope, the deviations are 0.5 nm at the maximum. The accuracy of the CD linearity is clearly improved by the high NA condenser lens.

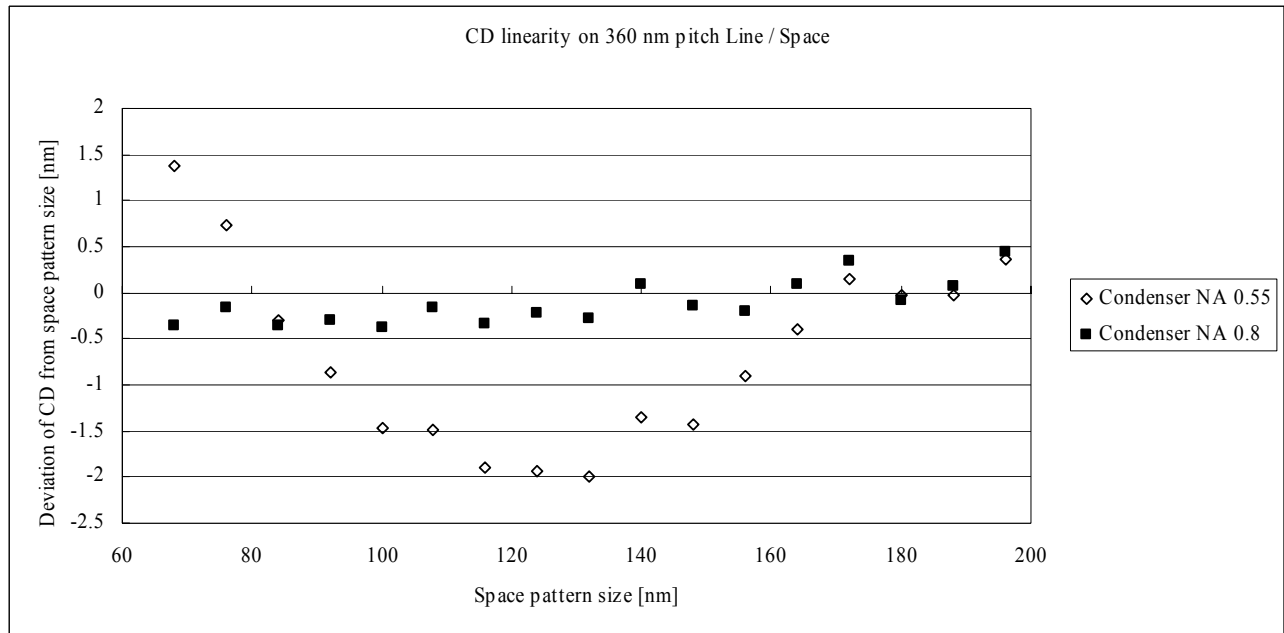


Fig. 3 Deviation of CD from space pattern size for 360 nm pitch line / space pattern on ArF att. PSM by simulation

### 3. CD REPEATABILITY IMPROVEMENT

Hole and dot patterns which nominal sizes are 0.3-0.5  $\mu\text{m}$  on a binary mask and an ArF att. PSM are measured with the current immersion microscope. Figure 4 shows 20 times repeatability of these patterns. CD repeatability on ArF att. PSM is more than the target value for 45 nm generation photomasks. CD repeatability on ArF att. PSM is inferior to that on binary mask. Figure 5 shows intensity profiles at a pattern edge. Peak of the intensity profile on ArF att. PSM is larger than that on binary mask. A large peak is highly susceptible to the influence of noise, and it will worsen CD repeatability. Intensity profile on ArF att. PSM with the high NA condenser is shown in Fig. 5. The peak of ArF att. PSM with the high NA condenser is lower than that with the current condenser. CD repeatability of the hole and dot patterns is shown in Fig. 6. CD repeatability with high NA condenser is 0.58 nm at pooled 3 sigma. The repeatability is obviously improved and is below the target value for 45 nm generation photomasks.

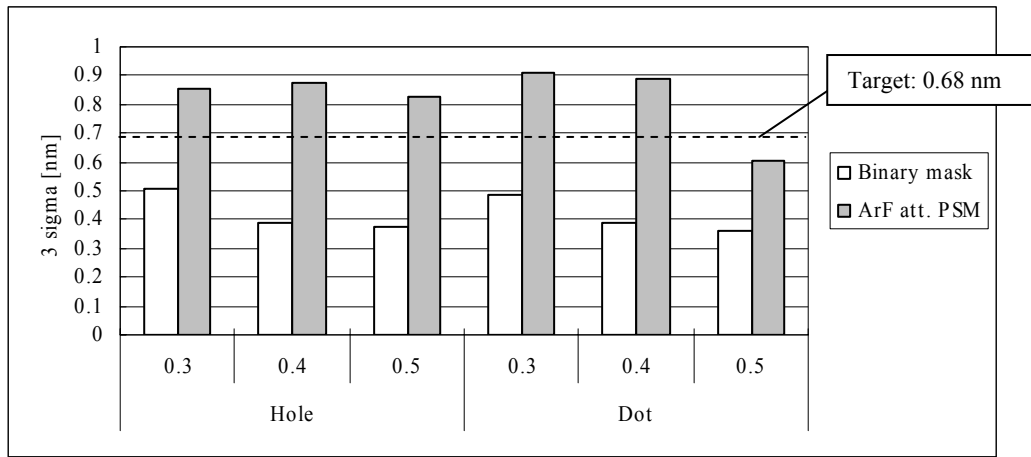


Fig. 4 20 times dynamic repeatability on hole and dot patterns with the current immersion microscope

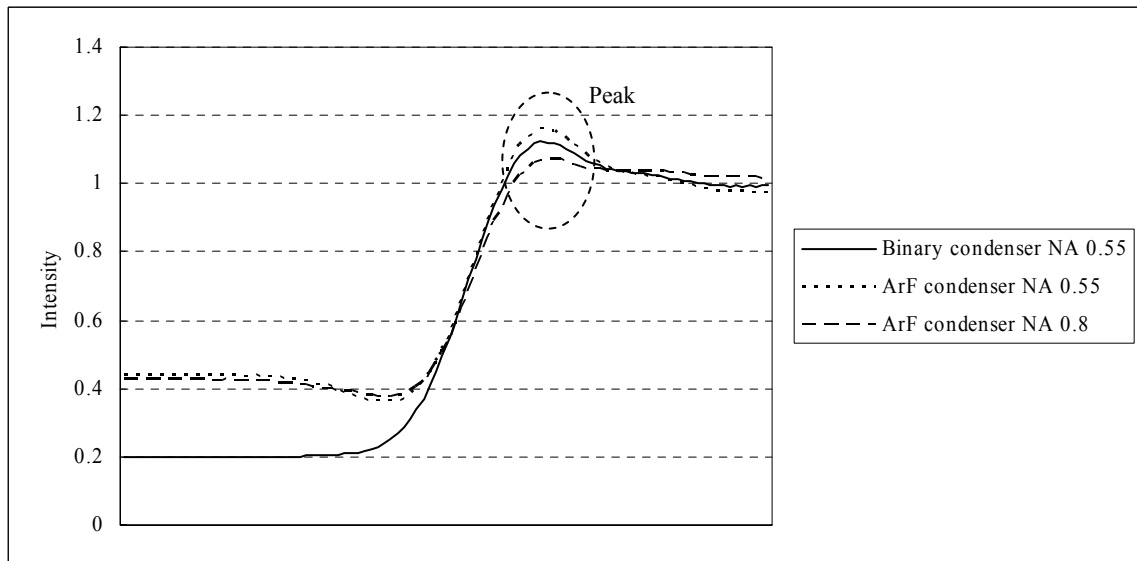


Fig. 5 Intensity profiles at pattern edge on binary mask and ArF att. PSM with the current condenser and high NA condenser

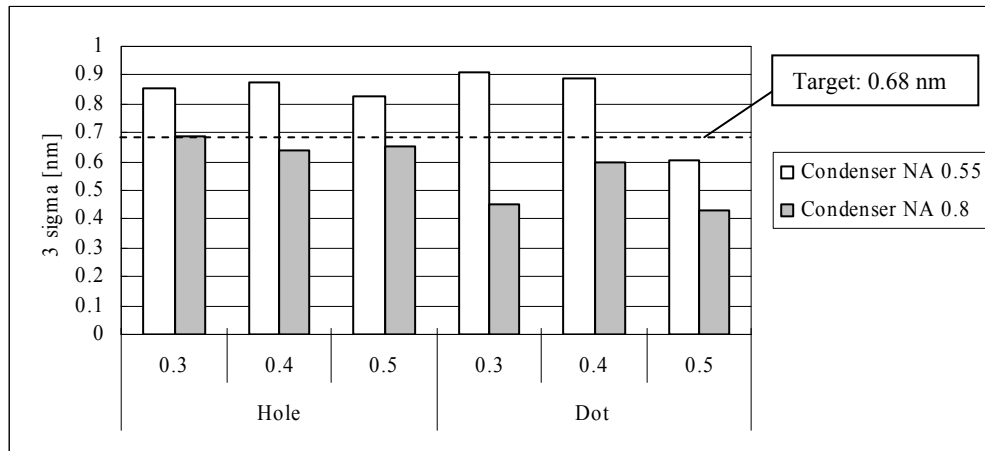


Fig. 6 20 times dynamic repeatability on ArF att. PSM with the current condenser and the high NA condenser

#### 4. CONCLUSION

An immersion microscope with high NA condenser lens is evaluated. There are two effects of high NA condenser lens, namely, CD linearity and CD repeatability. The simulation result indicates the high NA condenser lens improves the accuracy of CD linearity using our calibration method. The experimental result demonstrates the high NA condenser lens reduces the peak of intensity profile and improves CD repeatability. As a result, an immersion microscope with high NA condenser lens is available for CD measurement of 45 nm generation masks.

The repeatability data is first performance data. There is a possibility that the repeatability will be improved after fine adjustments.

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