



A novel method of partial coherence measuring for the illumination system and its defocus performance analysis[☆]



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ABSTRACT

Partial coherence (generally represented by σ) is one of the important parameters of lithographic tool to assess the performance of pupil fill. In this paper, a novel method of partial coherence measurement for the illumination system is proposed. Statistical results of measured σ by the proposed method are analyzed. The dependence of partial coherence on the defocus, which is the distance from the measuring position to the best image plane, is also investigated. The simulation results prove the effectiveness of this method, and with the defocus increasing, the measured partial coherence decreases. Generally, if three times of the standard deviation is required to be 1×10^{-3} , the amount of defocus should be less than 96 μm .

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1. Introduction

As the speed of integrated circuits (IC) increasing, the individual device critical dimensions (CD) are required to be tighter and tighter. As a result, CD variation across the semiconductor chip has become one of the limiting factors in IC manufacturing. Compared to the other major source of CD variation (mask, resist processing, metrology), imaging optics are the primary contributor to image non-uniformity. As lens aberrations are continuously reduced, the dose non-uniformity and local changes in the partial coherence σ of illumination optics have been proposed as primary cause of across chip linewidth variation [1]. According to the previous investigation, different partial coherence values might be used for different types of features (i.e., for printing isolated lines, is advantageous to use smaller partial coherence values. For tighter pitches, higher partial coherence values result in increased resolution) [2]. In addition, σ variation usually leads to the changes of depth-of-focus and image contrast which would strongly influence the performance of lithographic tool [3,4]. So, rapid measurements of σ variation are very useful for process engineers to optimize exposure tool and process condition. Many works and patents have investigated the performance of pupil fill including the partial coherence. Typically, by utilizing a “negative pinhole” and exposing positive photoresist, Kirk et al. presented a method of in situ partial coherence

measurement [5]. Grodnensky et al. proposed a method of measuring the partial coherence uniformity. It is based on the high sensitivity of σ variation to the length of macroscopically large diamond-shape marks printed in photoresist [6]. Watson et al. measured the partial coherence uniformity by using quadrant apertures. The illumination reaching the wafer plane is measured with a photodetector [7]. In all of these methods, σ is measured on the wafer plane after the litho-tool has been packaged. The lens aberration cannot be excluded although it is small. Moreover, resist exposure is also needed. These methods not only cost high expenditure, but also depend on the resist development.

In this paper, a novel method of the partial coherence measurement for the illumination system is proposed. A pin-hole is located at the reticule such that the illumination source image is imaged through the pin-hole via the lens on to the photosurface of CCD camera. Because of the notable feature of CCD such as high sensitivity, fast response, small image distortion and so on, partial coherence can be measured instantaneously and rapidly by this method. It is more suitable for σ detection in the designing process of the illumination system. Statistical results of measured σ by the proposed method and the dependence of partial coherence on the defocus are analyzed.

2. Theoretical analysis

2.1. Principle of partial coherent illumination

In order to establish a mathematical description of intensity on the wafer, we first describe the electric field transmittance of a mask pattern $t_m(x,y)$. As shown in Fig. 1, the mask is in the x - y plane and

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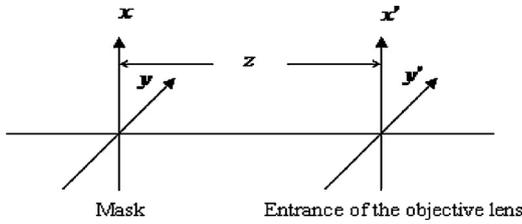


Fig. 1. Coordinate system of partial coherent imagery.

$t_m(x,y)$ has in general a magnitude, phase and vector direction. For a simple chrome-glass mask, $t_m(x,y)$ is 1 under glass and 0 under the chrome.

Let the $x'-y'$ plane be the entrance of the objective lens, and z be the distance from the mask to the entrance. Defining the spatial frequencies of the diffraction pattern as $f_x = nx'/z\lambda$ and $f_y = ny'/z\lambda$, the electric field of the diffraction pattern is given [8],

$$T_m(f_x, f_y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E_i(x, y) t_m(x, y) e^{-2\pi i(f_x x + f_y y)} dx dy \quad (1)$$

where E_i is the electric field incident on the mask. In Eq. (1), the diffraction pattern is just the Fourier transform of the mask pattern transmittance.

Due to the finite size of the objective lens (always described by numerical aperture $NA = n \sin \theta$, θ is the diffraction angle), not all the diffracted light passes through the lens. We define the pupil function P of the objective lens,

$$P(f_x, f_y) = \begin{cases} 1, & \sqrt{f_x^2 + f_y^2} < NA/\lambda \\ 0, & \sqrt{f_x^2 + f_y^2} > NA/\lambda \end{cases} \quad (2)$$

Since diffraction gives the Fourier transform of the mask, objective lens is designed to give the inverse Fourier transform of the diffraction pattern. The resulting image would resemble the mask pattern. Final expression for the electric field at the image plane is

$$E(x, y, f'_x, f'_y) = F^{-1}\{T_m(f_x - f'_x, f_y - f'_y)P(f_x, f_y)\} \quad (3)$$

and the image intensity is

$$I(x, y, f'_x, f'_y) = |E(x, y, f'_x, f'_y)|^2 \quad (4)$$

where $f'_x = \sin \theta' / \lambda$, θ' represents the angle of the incident ray. With an incident ray propagating perpendicular to the mask plane, $f'_x = 0$ and $f'_y = 0$.

If the illumination of the mask is composed of light coming from a range of angles rather than just one angle, the illumination is called partially coherent. We characterize the range of the angles as partial coherence σ which is defined as the sine of the maximum half-angle of the illumination cone divided by the objective lens numerical aperture:

$$\sigma = \frac{n \sin \theta_{\max}}{NA} \quad (5)$$

In partially coherent, the full aerial image is obtained by integrating the intensity over the extended source with an arbitrary shape. The source can be defined by a source function, $S(f'_x, f'_y)$, which is just the intensity of the source as a function of position. The total intensity of the image is then

$$I_{\text{total}}(x, y) = \frac{\int \int I(x, y, f'_x, f'_y) S(f'_x, f'_y) df'_x df'_y}{\int \int S(f'_x, f'_y) df'_x df'_y} \quad (6)$$

creating pupil coordinates in ' σ ' space,

$$\sigma_x = \frac{f_x \lambda}{NA}, \quad \sigma_y = \frac{f_y \lambda}{NA} \quad (7)$$

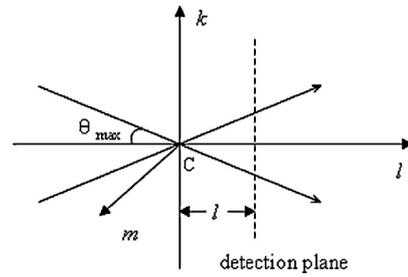


Fig. 2. Schematic that the detection position is not on the BIP.

The source shape function S can be normalized as

$$\tilde{S}(\sigma'_x, \sigma'_y) = \frac{S(\sigma'_x, \sigma'_y)}{\int \int S(\sigma'_x, \sigma'_y) d\sigma'_x d\sigma'_y} \quad (8)$$

so that

$$I_{\text{total}}(x, y) = \int \int I(x, y, \sigma'_x, \sigma'_y) \tilde{S}(\sigma'_x, \sigma'_y) d\sigma'_x d\sigma'_y \quad (9)$$

2.2. Intensity distribution when there is a defocus

In many cases, the real source shape can be approximated by the 'designed' source shape (the idealized top-hat illumination) convolved with an illumination point spread function (PSF). Under the condition of pin-hole imaging, often, the illumination PSF can reasonably be approximated as a Gaussian. When the pin-hole is not set on the BIP (best image plane, that is the mask plane on which the CCD can capture the pupil image perfectly), electric field incident on the mask in Eq. (1) should be modified as

$$E'_i(x, y) = \exp \left[\frac{-(k^2 + m^2)}{|l| \times n \sin \theta_{\max}} \right] \times E_i \quad (10)$$

where l is the amount of defocus. " $|l|$ " is an absolute value sign. The schematic is shown in Fig. 2.

C is any point on the mask. We establish a coordinate system $m-l-k$ and make C be the origin. $m-C-k$ represents the mask plane. m and k are, respectively, the vertical and horizontal coordinates. When the defocus l is equal to zero, m and k are equal to zero too, and $E'_i(x, y) = E_i(x, y)$. Therefore Eq. (10) is a more common form of electric field incident on the mask.

3. Simulation and discussion

The schematic diagram of the partial coherence measurement system is shown in Fig. 3. It is composed of pin-hole, lens and CCD camera. The pin-hole is located on the mask plane such that the illumination source image is imaged through the pin-hole via the lens on to the photosurface of CCD. In order to meet the requirements of Fourier transform, the centers of pin-hole and the photosurface

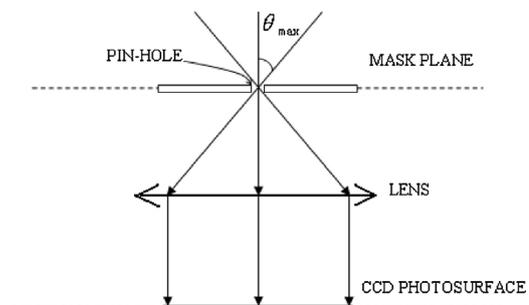


Fig. 3. Schematic of partial coherence measurement system.

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