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A study of the impact on telecentricity to the illumination system based on CCD imaging

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ABSTRACT

One of the important properties of the illumination system is of determining telecentricity for the realization of the place of wafer in the optical lithography. In this paper, we present numerical simulations of the optical imaging using four different illumination models and based on CCD imaging. We simulate the imaging of light source for different illumination pupil distributions and determine the energy centroid through the imaging of the conventional illumination which exist telecentricity of 11 mrad. Furthermore, we discuss the influencing factors of two aspects on telecentricity. One is the non-uniformity of light intensity distribution, and the other is pinhole defocus in the wafer. The range between the non-uniformity of light intensity distribution and pinhole defocus are quantified by computing the allowed telecentricity error in the illumination system. Finally, experiments have verified telecentricity measurement feasibility and validity. The presented scheme that with CCD imaging instead the actual wafer which saves cost and improves the accuracy in the optical lithography. In comparison with the measurement methods of convention the CCD imaging has a series of advantages such as fast response, high sensibility, high precision and the measurement is carried out on-line.

1. Introduction

The acceleration of integrated circuit (IC) miniaturization is challenging scientists and engineers to push the limit of physics by even more precise engineering and innovations. To achieve nanometer feature sizes, either the working wavelength has to be reduced [1], or alternative techniques of pattern transfer such as nanoimprinting lithography (NIL) [2], surface-plasmon polartions lithography [3] have to be adopted. However, optical lithography has still been the most widely used microfabrication technique because of its ease of repetition, effective cost and suitability for large-area [4]. But the characteristic feature size of IC has been shrinking for outpacing introduction of shorter-exposure wavelengths and pushing up requirement of higher resolution in the optical lithography. As a result, the depth of focus (DOF) becomes shallower, and the focus budget becomes tighter [5]. Therefore, the control of critical dimensions (CDs) becomes more and more important for high speed devices [6] and the imaging place across the exposure field becomes more and more critical [7]. CD uniformity is one of the most significant parameters which can evaluate the total performance of the lithography tools. A lithographic tool needs to maintain the CD of the printed features within 10% variation typically over the field [8]. All the time, CDs have been investigated in the developing of illumination system [9–16], Among all the CD error components, across chip linewidth variation accounts for the largest part of the CD budget and the most challenging in process development and control [9], and these budgets arise from the exposure tool, reticle and resist process [7]. To meet such a tight modeling accuracy, illumination system has drawn attention due to its impact on the imaging, for example, horizontal–vertical bias [9], exposure latitude [10], iso-dense bias [11], partial coherence [17], off-axis illumination [18], polarization [8], telecentricity [19], ellipticity [6], uniformity [20], and stray light [21]. It means that the illumination system could be influenced by many aspects in the manufacture of IC. So it is reasonable for us to introduce a general model to study the illumination system of lithography. In this paper, we mainly investigate telecentricity.

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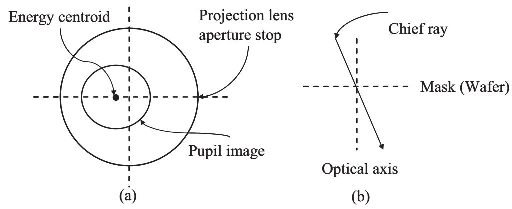

Fig. 1. The representation of (a) an energy centroid at the aperture stop of the projection lens and (b) the defined telecentricity at the mask and wafer.

Telecentricity as one of the most important property of optical lithography tool may cause pattern shift or CD asymmetry [13,14]. Based on aerial image simulation with measured non-telecentricity, its effect on sub-70 nm device patterning was discussed by SHIN et al. [22]. Experimental data showed that some of pupil-fills appeared more that 70 mrad of source displacement error and it might cause serious pattern shift and asymmetry. In the illumination system, minimizing the illumination telecentricity error has become one of the key points to realize devices with smaller feature sizes [20], because the error results in asymmetric image distortion. There are three main sources that cause non-telecentricity (NT) that are the exit pupil NT, reticle side NT, and source displacement error (SDE) [13]. A grating pinhole for measuring the effective illumination source shift in exposure tools had been established by Kazuya Sato et al, and this methodology enables people to measure the components of the telecentricity errors [20]. At present, there are three key methods that pupil measuring method of the grating-pinhole mask, Fresnel zone plate (FTP), and source metrology instrument (SMI) of Litel measure the telecentricity. All of these methods measure the telecentricity on the wafer plane after the litho-tool being packaged and photoresist exposure. It is difficult to exclude the errors caused by projection lens and photoresist exposure. Moreover the resolution will be affected by the performance of photoresist.

Based on the analysis above, in this paper, using numerical simulations and experiments, we report a phenomenon that happens between pinhole and CCD with a lens being wafer placed on a plane to monitor the telecentricity in the illumination system. The presented scheme based on CCD imaging instead of the actual wafer plane can save cost and improve the accuracy. In this method, the relative location at selected points of captured imaging on CCD is obtained, which determines the value of telecentricity.

2. Principle

It is known as exit wafer side NT when the chief rays at the wafer plane are non-parallel. Telecentricity is defined when the chief ray of each field point and optical axis are non-parallel, which is the angle of incidence at the wafer and is shown in Fig. 1. The energy centroid as a performance of pupil-fill image will be used to evaluate the telecentricity. The telecentricity is measured through exposing test patterns at different vertical positions of the wafer plane by using four illumination model (conventional, dipole, annular, and quadrupole as shown in Fig. 2).

The pinhole camera test module [23] is used to measure telecentricity in this work. Using angular spectrum theory of diffraction discuss the light identify distribution of pupil image in the photosurface of CCD. The u is the image side aperture angle of the illumination system, which is the maximum angle of incidence light in silicon surface, the relationship between the aperture angle u of illumination system and the image side numerical aperture NA of the projection lens is:

$$u = \sin^{-1}\frac{\sigma NA}{M} \tag{1}$$

where σ is part partially coherent, M is reduction magnification of projection objective.

The pinhole coordinate system (x, y, z) and the photosurface coordinate system (x', y', z') of the CCD are defined as shown in Fig. 3. The angle θ' is formed between plane wave and the k axis when arbitrarily propagating plane wave incidence pinhole, and the angle ϕ' is also formed between k plane and the x-axis, then the plane wave at the complex amplitude distribution of the pinhole plane:

$$u_0(x, y) = A\exp(ik\sin\theta'(\cos\phi' x + \sin\phi' y)) \tag{2}$$

where A is complex constant, $k = 2\pi/\lambda$, λ is wavelength of light source. Due to the finite size of the pinhole, not all the diffracted light passes the pinhole. We define the pupil function $\tilde{P}$ of pinhole,

$$\tilde{P}(f_x, f_y) = \begin{cases} 1, & \sqrt{x^2+y^2} \le \dfrac{D}{2} \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where D is diameter of pinhole.

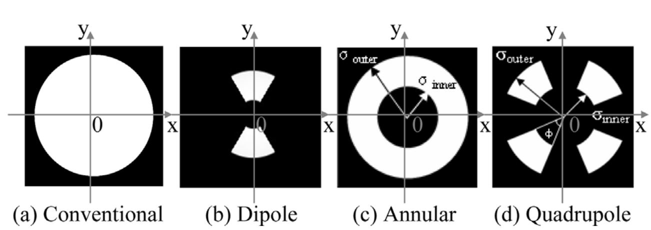

Fig. 2. Light distributions in the lens pupil plane under ideal (a) conventional illumination, (b) dipole illumination, (c) annular illumination, and (d) quadrupole illumination conditions.