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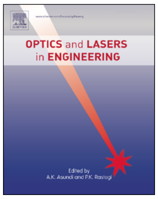

Experimental study of Talbot imaging moiré-based lithography alignment method

Jiangping Zhu [a,b,c,*], Song Hu [a], Pei Zhou [a,c], Junsheng Yu [b]

[a] Institution of Optics & Electronics, Chinese Academy of Sciences, Chengdu 610209, China
[b] School of Optoelectronic Information, University of Electronic Science and Technology of China, Chengdu 610054, China
[c] University of Chinese Academy of Sciences, Beijing 100039, China

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ABSTRACT

A four-quadrant gratings alignment method was presented for proximity lithography, which experimentally achieved the alignment accuracy of nanometer level. The alignment marks consist of gratings with slightly different periods, leading to different Talbot distances with the same monochromatic planar wave. The contrast of moiré fringe varies with the gap between mask (alignment mark) and wafer (alignment mark), which will affect the phase comparison, and induce more errors as well. This paper concentrates on the optimization of parameters of alignment marks to achieve the resulting moiré fringes with an optimum contrast. By simulation and experiment, we investigate effects of the gap on the contrast, based on which, the design principle of alignment marks is concluded, and it is helpful to the practicability with our proposed alignment method.

1. Introduction

The alignment system plays a crucial role in lithography, which determines the final performance of integrated circuit and micro-nano components [1]. It is thus regarded as one of the three key lithography technologies [1]. The relative positioning (overlay) during exposure is achieved by the alignment system. As the feature size decreases, the conventional optical projection lithography faces many challenges such as lens material and design, mask fabrication and special resist material [2]. According to 2012 international technology roadmap for semiconductor (2012 ITRS), the candidates of 32 nm node below are imprinting lithography, 13.5 nm EUVL and 193 nm (ArF) immersion lithography. Imprinting lithography will be possibly applied in near future for its low cost instead of sophisticated lens and illumination etc. [2].

Recently, many alignment methods for proximity lithography emerge such as the geometric imaging method, the intensity-based detection method and the phase-based signal detection method [3–9]. These methods with low alignment accuracy and poor process applicability do not satisfy the requirements of the current nanometer-level alignment. For nanoimprint and X-ray lithography, a dual-gratings moiré alignment method was reported in Refs. 10–15, and great successes have been achieved in the form of many theoretical and experimental works. Lately, our group has proposed a four-quadrant gratings alignment method for proximity lithography like nanoimprint and X-ray lithography, and has already achieved an alignment accuracy of nanometer level [16–19]. However, several critical issues such as optimizing the parameters of marks and how the gap between them affects the contrast of moiré fringe have not arrived at a solution. The period difference between gratings will result in inconsistent contrasts among moiré fringes if the wafer is located at some positions. Besides, the π-phase shifting of moiré fringe appears as well. All these will go against accurate alignment.

In this paper, we focus on optimizing the parameters of alignment marks including the relationship between grating periods and the gap. Through theoretical analysis and experimental investigation, the design principle of alignment marks is concluded, and the moiré fringes with an optimum contrast are obtained to perform the alignment experiment.

2. Alignment principle

As shown in Fig. 1, the alignment marks consist of four gratings. The 2th and 4th quadrants of mask alignment mark have the period P_1, while the remaining quadrants have the period P_2 ($P_1 \approx P_2$). The wafer alignment mark has a complimentary placement with that of the mask. The original gap between mask and wafer is denoted by G. During alignment, moiré fringes forms

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[*] Corresponding author at: Chinese Academy of Sciences, Institution of Optics & Electronics, PO Box 350, Shuangliu, Chengdu 610209, China.
Tel.: +86 1398 070 1339.
E-mail address: zsyioe@163.com (J. Zhu).

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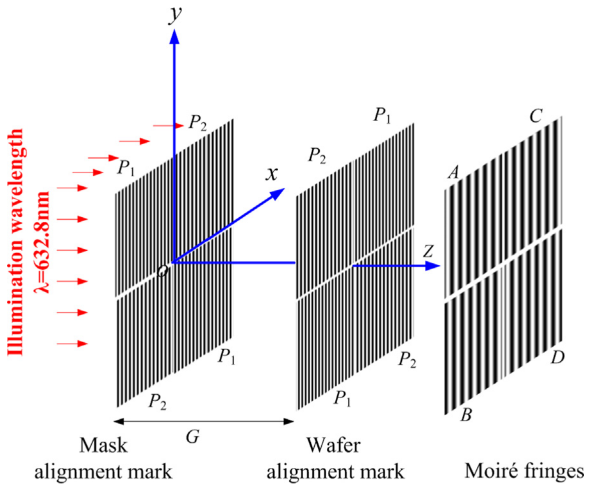

Fig. 1. Alignment marks and moiré fringes: the shaped "+" is used for coarse alignment. Original gratings in moiré fringes were removed. The incident illumination is a plane wave of unit intensity.

when the wafer alignment mark is superposed on the plane of Talbot imaging of the mask alignment. Here, four sets of sub-moiré fringes have the same period

$$P_M = \frac{P_1 P_2}{|P_2 - P_1|} = \frac{P_1 P_2}{\Delta P} \tag{1}$$

By obtaining the phase difference $\Delta\delta$ between sub-moiré fringes A and B or C and D, the misalignment in x-direction can be expressed by

$$\Delta x = \frac{\Delta\delta}{2\pi} \frac{P_1 P_2}{P_1 + P_2} \tag{2}$$

where, alignment marks are designed to identify the alignment in x-direction for the case of $\Delta\delta_{AB} = -\Delta\delta_{CD} = 0$. The alignment in y-direction is similar with the case of x-direction.

3. Alignment mark self-image

The well-known Talbot effect referred to self-imaging that the field behind the grating is not only periodic in axial direction, but also in lateral direction owing to the periodicity of the grating [20–26]. A monochromatic planar wave of unit amplitude is modulated by the grating in the form of multiple symmetrical diffraction orders, which spatially recombine to form a series of grating self-images. These grating self-images have an optimum contrast at some particular planes determined by $G = kZ_p/2$ ($k = 0,1,2,3\ldots$), and $Z_p = 2P^2/\lambda$ is Talbot distance of grating P [20]. Only k is even, the self-image can reappear itself. When k is odd, the grating self-image can also reappear but π-phase shifting occurs [20]. As illustrated in Fig. 1, the contrast of moiré fringes varies with the gap G, such that moiré fringes disappear and reappear periodically when G increases or decreases. When G is adjacent to these particular planes, the moiré fringe remains visible with a lower contrast [26]. While the G is placed middle two adjacent particular planes, the moiré fringe is not visible [26]. For the case of our proposed alignment scheme, alignment marks consist of four sub-gratings with periods P_1, P_2 (see Fig. 1). The moiré fringe pattern is composed of four sub-moiré fringes but only contrasts of diagonal sub-moiré fringes vary in the same manner.

For our proposed alignment method, several factors below need to be carefully checked:

(a) Grating period P_1 should be approximately equal to P_2 for ensuring an apparent magnification. Generally, it is reasonable when $P_2 \approx 1.1\ P_1$ [17];
(b) Optimum contrast for moiré fringe should be achieved as far as possible for phase comparison ($\Delta\delta$).
(c) Note that $Z_{P_1} < Z_{P_2}$ because $P_2 > P_1$ for our design scheme;
(d) π-Phase shifting must be avoided for all sub-moiré fringes during alignment, otherwise incorrect phase comparison inducing erroneous misalignment will occur [see Section 2].
(e) Note that the intensity of Talbot imaging of mask alignment mark decreases gradually with light propagating along z-direction, which will reduce the contrast of moiré fringes even if $G = kZ_p/2 (k = 0,1,2,3\ldots)$ [21].

Hence, according to the characteristics of Talbot imaging of grating described above, the grating imaging can repeat itself completely at distances kZ_p ($k = 1,2,3\ldots$) from the grating. Simultaneously, the good contrast of Talbot imaging of grating should be located near kZ_p. The selection of G, i.e., the placement of wafer alignment mark, should be governed by conditions (a)–(e) and simultaneously satisfy the following relationships

$$kZ_{P_1}/2 \le G < kZ_{P_1}/2 + Z_{P_1}/4, (k = 2,4,6\ldots) \tag{3}$$

$$kZ_{P_2}/2 - Z_{P_2}/4 < G \le kZ_{P_2}/2, (k = 2,4,6\ldots) \tag{4}$$

However, considering condition (e) and the cost of illumination, $k = 2$ is preferred. Thus Eqs. (3) and (4) become

$$Z_{P_1} \le G < 5Z_{P_1}/4 \tag{5}$$

$$3Z_{P_2}/4 \le G < Z_{P_2} \tag{6}$$

Within the intersection Eqs. (5) and (6), one can select certain position G to ensure that four sub-moiré fringes have an almost uniform and good contrast and π-phase shifting cannot appear. Once G is fixed, the alignment system performs accordingly the alignment operation.

It would be specially mentioned when wafer alignment mark is placed at a very small position from mask alignment mark, that is, G meets simultaneously

$$0 \le G < Z_{P_1}/4 \tag{7}$$

$$0 \le G < Z_{P_2}/4 \tag{8}$$

Four sub-moiré fringes likewise possess a good contrast but here G may be very small to 10 μm or so, which may be still appropriate to the alignment if the lithography technique condition is permitted. Here, we refer to the intersection between Eqs. (5) and (6) as "Case 1" and the counterpart for Eqs. (7) and (8) as "Case 2", respectively. How to select depends on the actual need. It should be expected that the analysis mentioned above can be how-to for engineers.

4. Experimental results and discussion

4.1. Influence of the gap on moiré fringe contrast

The experiment setup is shown in Fig. 2. The alignment marks in our experiment are fabricated by electron beam lithography (EBL) at Institute of Microelectronics of Chinese Academy of Sciences (IME, CAS). A He–Ne laser (25 LHR 151) with wavelength