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Hybrid approach for the design of mirror array to produce freeform illumination sources in immersion lithography

Lidong Wei, Yanqiu Li*

Key Laboratory of Photoelectronic Imaging Technology and System of Ministry of Education of China, School of Optoelectronics, Beijing Institute of Technology, Beijing 100081, PR China

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ABSTRACT

Source and mask optimization (SMO) has emerged as a key resolution enhancement technique (RET) for 45 nm technology node and below in lithography. The design method of freeform illumination sources predicted by SMO is significant for the scanner development. We present a hybrid approach combining simultaneous and sequential approaches to optimize the tilt angles of the mirrors to produce multi target freeform illumination sources accurately and quickly. The size of spot reflect by plane mirror can be easily controlled by changing different microlens arrays with appropriate focal length, which reduce the complexity of the system and makes it more flexible to produce the specific freeform sources compared to curving the mirrors used in previous work. The relationship between the tilt angles of plane mirrors and the positions of the spots in the pupil is obtained by chief ray tracing. Using the hybrid approach the freeform illumination sources required by SMO can be designed by merely adjusting the tilt angles of mirrors without changing other parameters of optical elements, which is most effective for both lithography tool manufacture and its applications. The real ray tracing results demonstrate that our design method is capable of creating multi freeform illumination sources with high transmittance, and confirm that the effectiveness of the hybrid approach for optimized design and control of mirror array in immersion lithography system.

1. Introduction

Currently, 193 nm immersion lithography is an indispensable role for the semiconductor industry. As shrinking of semiconductor devices accelerates, SMO is indeed a promising RET method for 45 nm technology node and below. SMO has been predicted that several kinds of freeform illumination sources are indispensable in a scanner to exposure different pattern structures [1–3]. Therefore the design method of multi freeform illumination sources predicted by SMO is significant for the scanner development.

Although it is possible to produce freeform sources with diffractive optical elements (DOE) [4,5], it still has light losses and background light due to the zero-order and high-order diffraction. Moreover, one DOE can only generate one predetermined illumination source which cannot meet the requirements of SMO. To overcome the limitations above, a mirror array is introduced to create freeform illumination sources by a mirror array [2,6,7]. The curvature of the mirror is subject to tight specifications to control the size of spots in the pupil reflect by the mirrors which make the mirrors hard to manufacture, and the fixed spot size usually may not meet the design requirements of freeform sources. And iterative algorithm is used in the design of tilt angles of the mirror array [7]. Simultaneous approach and sequential approach could be used to optimize the tilt angles of mirrors, but both of them have their own limitations. The simultaneous approach can decrease the error quickly at the beginning but the error falls in to shock state and fails to produce the target sources. While the sequential approach can produce the target sources accurately but it is time costly.

In this article, we present a hybrid approach for the design of the mirror array to produce the multi target freeform illumination sources in immersion lithography system. The hybrid approach combining simultaneous and sequential approaches optimizes the tilt angles of mirrors to produce freeform illumination sources accurately and quickly. Another attractive and effective work is that the size of spot can be controlled arbitrary by changing different microlens array with appropriate focal length rather than curving the mirrors which reduce the complexity of the mirror array and makes it more flexible to produce the specific freeform sources. The relationship between tilt angles of the mirror array and the positions is obtained by chief ray tracing in CodeV

* Corresponding author.
E-mail address: liyanqiu@bit.edu.cn (Y. Li).

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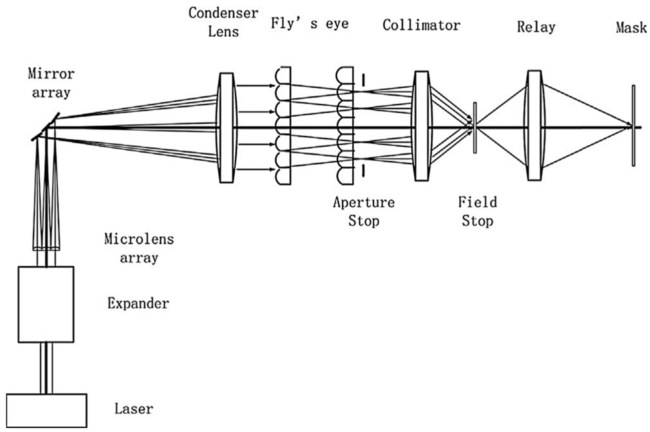

Fig. 1. Schematic diagram of an illumination system including the mirror array.

(Synopsys, Inc.). Four target freeform illumination sources, which are derived based on the SMO algorithm introduced by our lab [3,8,9], are designed. After a qualified initial source are obtained, another three freeform illumination sources are designed by merely adjusting the tilt angles of mirrors rather than changing other parameters of optical elements, which is most effective for both lithography tool manufacture and its applications. The real ray tracing showed that the sources obtained by the mirror array closely match the target sources with high transmittance. It confirms that our design method is capable of creating kinds of multi freeform illumination sources accurately and quickly.

The paper is organized as follows. The principle of mirror array is described in Section 2. The optical considerations are listed in Section 3. The optimization design of mirror array is provided in Section 4. Then the simulations are given in Section 5. Finally, the conclusions are given in Section 6.

2. Principle of the mirror array to produce the multi target freeform illumination sources

An illumination system which includes the mirror array is schematically shown in Fig. 1. The beam exiting from the 193 nm laser passes through the beam expander, and then enters the microlens array which is used to split the beam into multi beams. The mirror array is arranged in the back focal plane of microlens array and also the front focal plane of the condenser. With adjusting the tilt angle of each mirror at the array, the intensity distribution of target illumination sources are produced in the pupil plane. Then the beam is homogenized by the fly's eye and uniformity illumination is obtained at the mask. In this article, we focus on the design and control the mirror array to produce the multi target freeform illumination sources.

The mirror array is composed of thousands mirrors that controlled the angular distribution of light to make a desired illumination source in the pupil where is the back focal plane of condenser lens. The number of microlenses at the array is equal to the number of mirror and each microlens is assigned exactly to one mirror. Each mirror can be tilted in the horizontal and vertical directions and reflects a spot in the pupil plane through the condenser lens. Changing the tilt angles of the mirrors will change the positions of the spots in the pupil plane and then change the illumination source shape. Thus an effective optimization approach is needed to arrange the thousands spots to match the multi target freeform illumination sources.

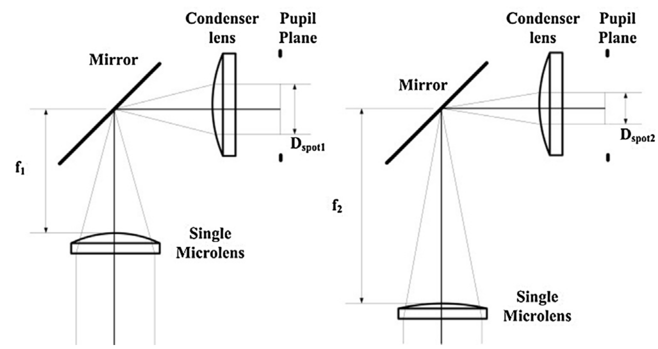

Fig. 2. Changing microlens array to adjust the size of spot.

3. Optical considerations

3.1. The optical design and determination of the shape and intensity distribution of spots

The condenser lens is to translate the angle distribution produced by the mirror array into the intensity distribution in the pupil plane. The relationship between incidence light angle and the focal length of the imaging lens f_c:

$$f_c \times \tan\ \theta = h = \frac{D_p}{2} \tag{1}$$

where h is the height of light incidence on the pupil plane, θ is the incidence angle of light, and D_p is the diameter of the pupil plane. Here D_p is 150 mm [10] and f_c is 425 mm according to Eq. (1).

The size of spot and the amounts of the mirrors are two significant parameters to design the mirror array. To reduce the complexity of the mirror array, we proposed a strategy to control the size of the spot by changing the microlens array with appropriate focal length rather than curving the mirrors shown in Fig. 2. The microlens combined with the condenser lens forms a two lens telescope that produces a real image of the subaperture of the microlens in the pupil plane, and the geometry diameter of the spot D_s can be written as,

$$D_s = D_m \times \frac{f_m}{f_c} \tag{2}$$

where the D_m is the diameter of the micro lens, and the f_m is the focal length of the microlens. According to Eq. (2), we can change microlens array with appropriate focal length to adjust the geometry of the spot in arbitrary that makes it more flexible to control the spot size. Moreover, all of the mirrors in our design are plane mirrors which are easy to manufacture compared to the curved mirrors.

On the other hand, Xalter [11] has concluded that at least 4000 mirrors are desirable in order to obtain an intensity distribution in the pupil plane. Therefore, after times choosing and simulating, the parameters of the mirror array and the microlens array are confirmed and shown in Table 1 and the f_m = 70 mm. And the layout of the proposed system is shown in Fig. 3.

However, the geometry shape is not accurate to represent the spot, and intensity distributions of spots reflected by the mirrors are indispensable inputs for the optimization approach. The beam incident on the microlens array is assumed to be a plane wave [12].

Table 1
Parameters of mirror array and microlens array.

Items	Unit size(mm)	Amount of units
Mirror array	0.5 × 0.707	5041
Microlens array	0.5 × 0.5	5041