Lithographic exposure latitude aware source and mask optimization

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Abstract

Extreme ultraviolet lithography systems use ultraviolet light with a wavelength of 13.5 nm, which cannot pass through the lens materials currently used, so extreme ultraviolet lithography objective systems use fully reflective optical elements. The loss of reflectivity of any one mirror results in a significant decrease in the luminous flux of the entire system. Therefore, in this paper, a high efficiency graded multilayer design method with least-square fitting approach was proposed to realize a high reflectivity multilayer coating for an anamorphic magnification EUV lithography objective with NA of 0.55. In this method, the parameters of the graded multilayer were calculated quickly by the least-square fitting method. Then calculate the reflectivity of each mirror separately. The design results show that the average reflectivity of each mirror is more than 60%, and the peak-valley value of reflectivity of each mirror is less than 4%.

Method

Graded multilayer films have different periodic thicknesses at different radial positions. By changing the thickness of the multilayer films at different positions on the mirror, we can achieve high reflectivity of the objective system by making the reflectivity of each point on the mirror uniform. The distance r between any point on the mirror surface and the optical axis determines the graded variation factor of the film thickness p, as in

$$p(r) = C_0 + C_2 r^2 + C_4 r^4 + \cdots + C_{20} r^{20}$$

Since the mirros of the anamorphic Magnification extreme ultraviolet lithographic objective system studied in this paper is symmetric about the meridian plane, there is only a translation Y0 in the y direction between the symmetry axis of the multilayer film and the optical axis of the reflector, and （1） can be written as follows:

$$p(r) = C_0 + C_2 x^2 + C_2 (y - Y_0)^2$$

Where C_0, C_2, Y_0 are thickness parameters of multilayer films and x, y are the coordinates of the sampling picking points on each mirror.

By writing the CODE V macro to obtain the light incident angle distribution on the mirrors M2, M3 and M5, the incident angle at each point on the mirrors is converted into the period thickness by (1). And then we expand and merge the nonlinear graded film thickness (2) and find that it conforms to the structure of a linear formula, so we use least squares to transform it into a linear matrix operation as follows:

$$\begin{bmatrix} \sum(x_i^4 + y_i^4 + 2x_i^2 y_i^2) & \sum(x_i^2 y_i + y_i^3) & \sum(x_i^2 + y_i^2) \\ \sum(x_i^2 y_i + y_i^3) & \sum y_i^2 & \sum y_i \\ \sum(x_i^2 + y_i^2) & \sum y_i & n \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} \sum(z x_i^2 + z y_i^2) \\ \sum(z y_i) \\ \sum z \end{bmatrix}$$

Where $A=C_2$, $B=-2C_2Y_0$, $C=C_O+C_2Y_0^2$.

Coating procedure

The pre-designed NA0.55 extreme ultraviolet lithography objective structure is shown in Figure 1, and the main design indexes are shown in Table 2.The RMS value of the integrated wave aberration of the bare mirror system is 0.0676λ.

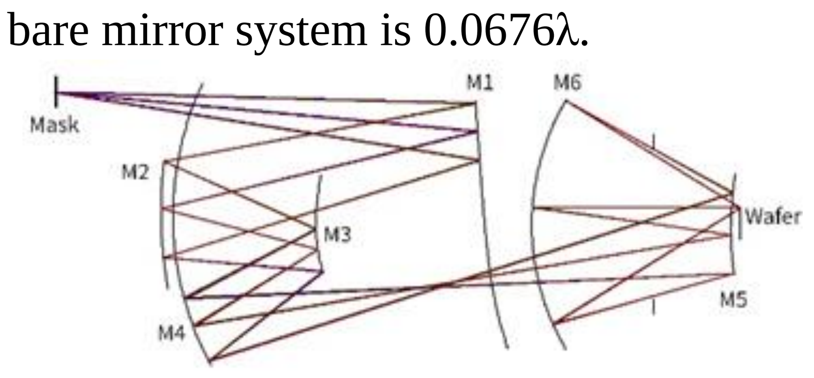

Fig.1. Objective structure diagram with NA of 0.55.

Table1. Main design specifications of projective objective

Parameter	Value
Wavelength/nm	13.5
Numerical aperture	0.55
Wavefront aberration/λ	0.0676
Chief ray angle of incidence on mask/(°)	≤6°
Image field of view/mm	26×0.5

We first traced the real ray for the objective mirrors and obtained the range of incident angles of the rays on the mirrors for each field of view. And then we coated periodic multilayer films for all six mirrors separately, and got the reflectivity of each mirror.

When a film layer is coated on a single mirror and the rest of the mirrors are assumed to be ideally reflective, the pupil intensity of the system can represent the reflectivity distribution of the light on that mirror. We can see that the incident angle range of M2, M3 and M5 mirrors is relatively large, and the reflectivity of the designed periodic film is lower than 35%, so we can deduce that these three mirrors are beyond the coverage of the reflectivity band of the periodic multilayer films. Therefore, we need to design the graded multilayer films to replace the periodic multilayer films for M2, M3, and M5.Then we calculate the parameters of the graded multilayer quickly by using the least-square fitting method. Lastly we calculate the reflectivity of each mirror separately.

Coating results

The graded variation parameters of the mirrors M2, M3 and M5 are shown in Table 2.

Table2. Parameters of graded multilayer films

Mirror	C0	C2	Y0
M2	1.0169	2.0472e-007	-241.0359
M3	1.0789	1.3615e-006	-197.6231
M5	0.9965	2.5864e-006	-104.2802

It can be seen from Figure 3 that after replacing the periodic film with gradient film on M2, M3 and M5, the reflectivity and its peak-valley value of the mirrors M2, M3 and M5 in the central field F2 have been greatly improved. The final coating results of the whole six mirros are show in figure 2 and figure 3.

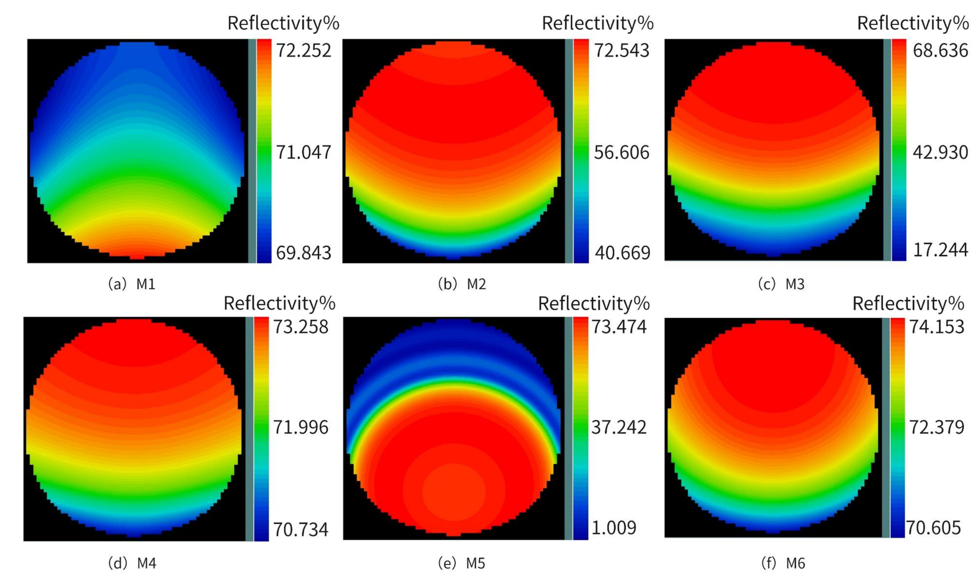

Fig.2. Reflectivity of the six mirrors by coating periodic multilayer films.

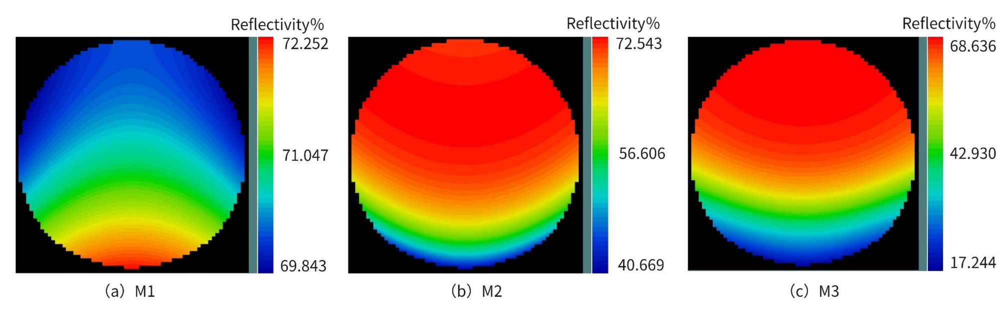

Fig.3. Reflectivity of the mirrors M2、M3、M5 by coating graded multilayer films.

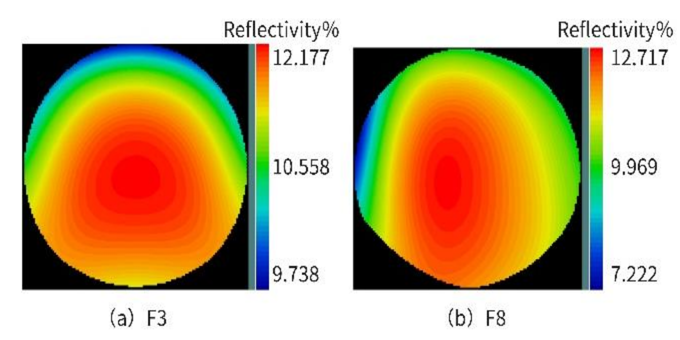

Fig.4. Reflectivity distribution and wavefront aberration distribution of the system.

The final multilayer design is M1, M4, M6: periodic multilayer, M2, M3, M5: graded multilayer. The graded multilayer parameters in this scheme are the optimal parameters that are quickly fitted using the least squares method. After all six mirrors are designed with multilayer film, the reflectivity of the objective lens containing film at the central field point F3 and the edge field point F8 is shown in figure 4. The wave aberration with and without multilayer films of the system are shown in Table 3.

Table 3 shows the wave aberrations at field F3 and F8 for the bare objective system and the system with multilayer film. It can be seen that the wavefront aberration of the extreme ultraviolet lithography objective system with NA of 0.55 reaches 0.0645λ for the bare lens system alone, and the RMS value of the coated objective system is 0.0871λ, which is only 0.0226λ more than that of the bare lens system and meets the image quality requirement.

Table3. Wave aberration of the systems without coating and with coating

Field Point	System with/without multilayer films	Wavefront aberration/λ
F3	Without	0.0676
	With	0.0959
F8	Without	0.0645
	With	0.0871

Conclusion

In this paper, a method that can quickly calculate the graded multilayer thickness parameters is proposed to realize the design of high reflectivity multilayers for Anamorphic Magnification extreme ultraviolet lithography objectives. The calculation rate is greatly improved and can be efficiently applied to large-aperture mirrors.