A Concept of Ultraviolet Lithography System and Design of its Rear Part using Artificial Intelligence for Starting Design

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Abstract: This paper describes a concept for designing a projection lens in lithographic optical system for 365 nm. Our approach for meeting this objective is to use the starting design obtained by artificial intelligence mode in Synopsys software. The proposed method describes the steps of getting a desired starting point of the optical system and the optimization problems in the optical system with a high numerical aperture.

1 INTRODUCTION

Optical lithography is a photographic process of using an optical image and a photosensitive film to produce the patterned silicon wafers in semiconductor manufacturing. The industry of integrated circuits mostly is using this technique in manufacturing process. In figure 1 it can be seen one type of projection optical lithography system. The source of ultraviolet light is the laser which shines through the illuminator, which expands, homogenizes, and conditions the beam in the condenser. Further, the light goes through a photo - mask, and the projection lens to the wafer which is coated with a photosensitive film (Rothschild, 2005). Many technologies have been proposed to improve the process of the optical lithography, but so far none has succeeded to replace lithographic systems (Harriott, 2001).

The driving forces which are pushing lithographic systems beyond the limits are decreasing wavelength and increasing numerical aperture, while the solution space is limited by several conflicting constraints such as diffraction limited performance, reasonable overall dimensions, minimum number of optical elements, availability of material, limits on the angles (Ulrich, 2000). Lithographic objectives are famous by its high quality, and by many challenges in optimization of the projection optical system (Levinson, 2005). Hereby, we proposed a simple concept in developing of the ultraviolet (UV) lithographic optical system which can simplify the work of the optical designer at the early stage of design.

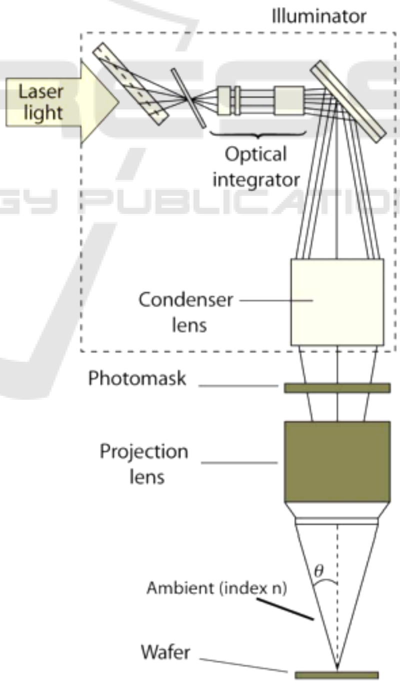

Figure 1: Schematic of the lithographic optical system.

We divide the total lithographic lens into two parts:

- Condenser (front) lens with removed back exit pupil, which could be understood as a reversed lens with the removed forward entrance pupil;

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- Projection (rear) lens with the removed forward entrance pupil (Figure 1).

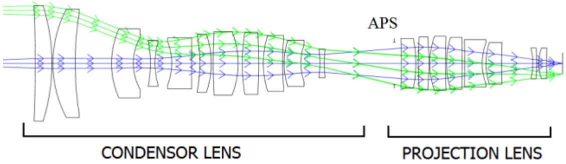

Figure 2: Schematic of the reference lithographic system.

Both parts can be designed separately as two objectives with removed entrance pupil and constraint of telecentric chief ray. An each part of the lithographic optical system must be optimized as good as possible in order to achieve diffraction limited optical system when we connect designed parts.

The desired specifications for proposed optical system we used from a reference UV lithographic system. Figure 2 shows our reference UV system: a lithographic objective for 365 nm with aberrations corrected up to diffraction-limit. The system is defined by next characteristics : F number is 1.2, the Gaussian image height is 9 mm, image distance is 22 mm and the magnification is - 0.2. The spectrum range of lithographic lens is ultraviolet (UV) with wavelengths: 362 nm, 365 nm and 368 nm; principle color is 365 nm. In our case we have split the total lithographic system at the place of aperture stop (APS) where the chief ray angle has a minimum.

The starting point for a projection (rear) part of the lithographic system was obtained by the artificial intelligence (A.I.) mode in Synopsys software, and optimized by the merit functions for transverse and OPD aberrations.

2 STARTING DESIGN OF THE PROJECTION LENS

In order to keep the specification of a total optical system we have derived the specifications of the projection part. Focal length 100 mm was chosen for the projection part in order to keep the total length of a reference system. We have calculated the field angle using formula (1)

$$\acute{\omega} = \mathrm{Arctg}\,(y'/f') \qquad (1)$$

where $\acute{\omega}$ is the chief ray angle, y' is gaussian image hight and f' is a focal length of the projection lens. The image distance we kept 22 the same as in a reference litographic system.

Successfully choosing the starting system at the early stages of development significantly shortens the overall planning time (Livshits, 2007). In the period of the wide applications of computers in optical design, the speed of the ray tracing itself increased thousand times, but the speed of new schemes creation is not so fast, approximately 2-3 times. The main reason is hidden in the unsuccessful starting point selection, If selected scheme doesn't have enough correction features, no computer can add them without optical designer. In order to obtain good starting point for projection lens we were using artificial intelligence (A.I) mode in Synopsys software.

Artificial intelligence capability is the expert systems program within Synopsys software. A general set of requirements may be input, and Macro will find the 10 best designs that most closely match them when the scale and aperture are adjusted as well as possible. Applied algorithm is one that employs a tree-structured logic wherein decisions are derived from the responses of a number of experts (their experience) in a particular field to a lengthy debriefing (Dilworth, 2013).

DSearch macro (Design Search) is searching through lens space in order to find an attractive starting point. We give it the desired system parameters and the number of elements we want, along with some target quantities to define the design goals. It constructs a series of candidate lenses, with initial dimensions assigned according to either a binary search scheme or randomly, depending on user input.

Table 1: Specifications for the starting point of design.

Specification	Value
Object distance	Infinite
Object height	Infinite
Marg. ray height	41.67 mm
F/Number	1.2
Chief ray angle	5.69 degrees
Focal length	100 mm
Gaussian image height	9 mm
Image distance	22 mm

The default option assigns element powers according to the bit in a binary number that is incremented at each cycle. Thus, if you request, a four-element lens, the first lens would have all negative elements taken from the binary number (0000). The next try would have one positive element, from the number 0001.

In Table 1 are presented the specifications for the starting point of our projection lens. It is desired that a bulge of the lithographic optical system possess more positive lenses. In order to achieve this goal we have been starting with the smaller system, with shorter focal length and smaller marginal ray height. In DSearch macro we have defined characteristics of our system:

```
TIME
DSEARCH 1 QUIET
SYSTEM
OBB 0 5.69 5
UNI MM
WAVL .368 .365 .362
END
GOALS
ELEMENTS 7
FNUM 1.2
BACK 2.1
STOP FIRST
STOP FIXED
GLASS POS
O S-FSL5Y
GLASS NEG
O PBM2Y
END
SPECIAL
ACM 3 1 1
ACC 5 1 1
M 0 100 A P HH 1
END
GO
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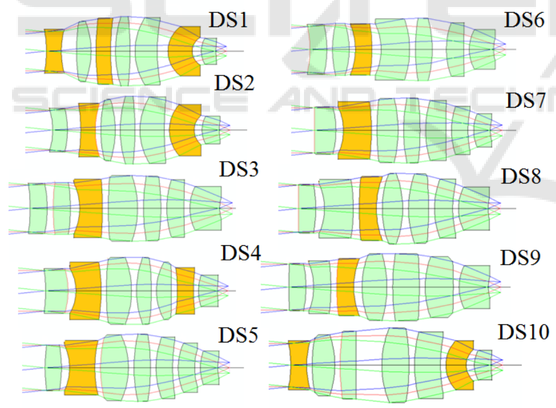

Figure 3: Starting points obtained by DSearch macro.

Section OBB 0 5.69 5 defines field angle 5.69 and marginal ray height 5. Next section WAVL .368 .365 .362 defines wavelengths; number of lenses ELEMENTS 7; Fnumber FNUM 1.2; back focal length, BACK 2.1. We demand aperture stop at the first surface STOP FIRST, STOP FIXED; section which defines minimum and maximum lens thickness ACM 3 1 1, ACC 5 1 1; and special section where we define constraint for telecentricity SPECIAL M 0 1 A P HH 1. In this particular case, estimated time is around 90 minutes, while DSearch macro is searching for 10 best candidates for starting design. We have defined in macro 7 elements (lenses) in order to decrease number of lenses in our design comparing it to the reference projection lens. Obtained 10 starting designs for projection part are shown in Figure 3. The positive lenses are marked by green, while the negative lenses are marked by yellow color. It can be seen that we reach our goal to get more positive lenses in the system bulge. The logical decision related to decreasing of the aperture is to have more positive lenses in a bulge. By comparing the transversal aberrations of all ten candidates and number of positive lenses in a bulge of the systems the seventh design search (DS7) was chosen as the most appropriate.

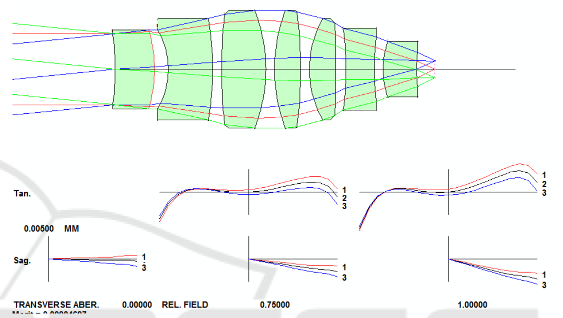

Figure 4: Starting point for projection lens obtained by DSearch macro.

DS 7 has one negative lens closer to the aperture stop; it is shorter than others obtained starting points with much better sagital transversal aberration in range 0.005 mm. On another hand, we obtained the optical system having the short focal length 9 mm and thin lenses. In the next step we have scaled focal length (f) to 100 mm. In this way we reached the desired characteristics of the optical system shown in Table 1. The chosen starting design DS7 is shown in Figure 4, having 6 positive elements of total 7 elements. After the chosen lens DS7 is scaled to focal length 100 mm, the transversal aberrations are in range 0.05 mm.

3 OPTIMIZATION OF THE PROJECTION LENS

The issue of optimization of the lithographic objectives is probably the most difficult one in the optical system optimization. Usually the modern UV lithographic objectives have more than twenty components having aspheric surfaces. That results in more than one hundred optimization variables. The most important constraints are the magnification, total track and telecentricity. (Mack, 2006) Considering all these issues, the optimization of the projection lens should be easier than the optimization of the total lithographic system because of the less optimization variables and less number of the lenses. However, the design of optical system with high aperture is challenging work. Increasing NA has meant increasing the acceptance angle of the lens (Kawata, 1989). This process has had to overcome significant challenges in optical design and fabrication because the lens must be near aberration-free and the image size must be kept large, ~4 mm x 26 mm. Despite these difficulties, the NA of projection systems has grown steadily, from 0.5 in around 1990 to over 0.8 in 2004, with plans to exceed 0.9 in the future.

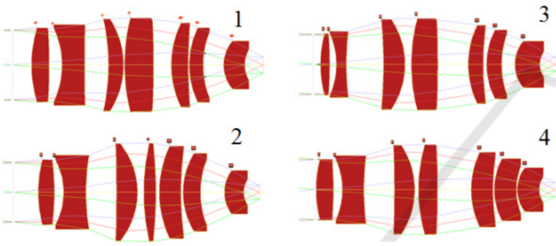

Figure 5: Steps of the optimization in design of projection lens.

Our referent lithographic system having NA 0,52, for 365 nm, was chosen in order to be designed just by the lenses, avoiding utilization of the mirrors (Born, 1999). The starting design DS7 of lithographic projection lens obtained in Synopsys was optimized in Synopsys by using a merit function for transversal and OPD aberrations as well in Zemax by using a default merit function for the best focus, RMS Spot Radius, Centroid RA 18x18 having the constraints for a telecentric chief ray. Figure 5 shows the few steps in the process of optimization. It can be seen that we have been keeping logic of projection lens having a bulge and positive lenses which decreasing numerical aperture.

In Table 2 are explained the few applied steps, in Synopsys software, during process of the optimization of the starting design. The final design of the projection part and its MTF (modulation transfer function) are shown in Figure 6.

Developed projection part is optimized close to diffraction limit for central field angle (Figure 6.) Longitudinal aberrations are in range 0.00112 mm, while distortion has to be more decreased up to zero. Total length of developed projection lens system is 310 mm what is one disadvantage compared to the reference projection part of total system. It could be improved in further work, where we intent to develop the total lithographic lens by connecting a projection part of system with the condenser part.

Table 2: Optimization steps of the projection lens.

Optimization step	Description
1. step	Starting design from 0.05 transv. aberration, aperture stop was added, design was optimized with default merit function, 3*6 full grid, constraints 35 mm max thickness, biggest weights for third order aberrations
2. step	New merit function with additional rays for wave front aberrations- full grid, bigger weights for astigmatic curve
3. step	Merit function with more additional rays in field zone for OPD (optical path difference)
4. step	Merit function for OPD, changing weights for particular aberrations in order to get better MTF on axis and transverse aberration scale

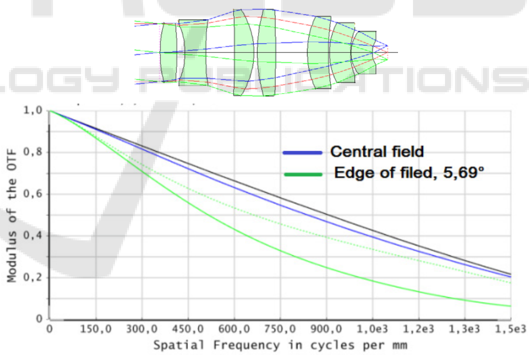

Figure 6: Designed projection lithographic lens with its MTF.

4 CONCLUSIONS

We have presented a method for designing projection part of lithographic lens using artificial intelligence for starting points which should to simplify the early stage in design of the lithographic optical system. By using Dsearch macro we showed the way how to obtain desired starting design with more positive lenses in a bulge of the lithographic system. Starting design of projection lens was optimized close to diffraction limited optical system, and the main steps in applied optimization were explained. In additional, designed projection part it can be more optimized in order to reach diffraction limited system. Proposed method can be easily adopted for the starting design of any optical system having more positive lenses. Further work will be design of front (condenser) part using artificial intelligence for starting design, and final design of total lithographic optical system.

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