Automated design of projection lenses for lithography based on global search algorithms

N. ZORIC I. SMIRNOVA A. KULESHOVA

STARTING DESIGN

One of the most challenging steps for an optical designer is how to start designing an optical system?
Usually, the successful optical design is closely related to the successful starting point selection. If selected the starting layout has enough correction features, optical designer could shorten overall time of work and reach the design goals much easier [1]. Therefore, currently the owners of optical design software are starting to provide the user with the possibility of automatically choosing the starting layout for the design process.
Lithographic objectives are famous for their high quality, and for many challenges in optimization of the projection optical system.
Hereby, we propose the method in the developing of ultraviolet (UV) lithographic projection lens by Synopsys software that is aimed to simplify the work of the optical designer at the early stage of design. We have divided the total set of lithographic lens into two parts:
Front part of lithographic objective with the removed back exit pupil which is understood as a reversed lens with the removed forward entrance pupil (Figure 1, right);
Rear part of lithographic objective with the removed forward entrance pupil (Figure 1, left). Following characteristics define the reference UV bi-telecentric objective, for 365 nm with aberrations corrected up to diffraction-limit: F number is 1.25, the Gaussian image height is 9.9 mm, image distance is 22 mm, magnification - 0.2 [2]. The starting points with glass models were obtained by Dsearch macro in Synopsys software. The rear part with FN=6, consisting of 10 lenses, has been designed in 20 minutes by Dsearch macro. While the front part with FN=1.25, consisting of 15 lenses has been designed for 20 hours approximately. Figure 2 and Figure 3 show the modulation transfer functions (MTF) of rear part and front part. The front part of lithographic objective was connected with the rear part by AI command - COMBINE (manual Synopsys) [3].

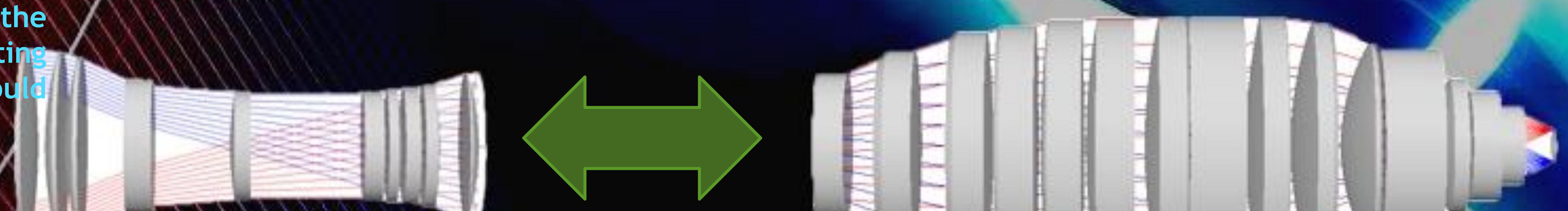

Figure 1.

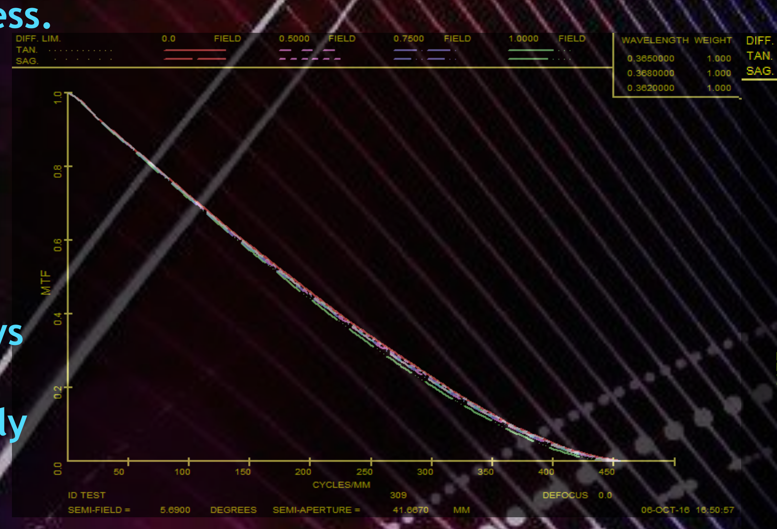

Figure 2.

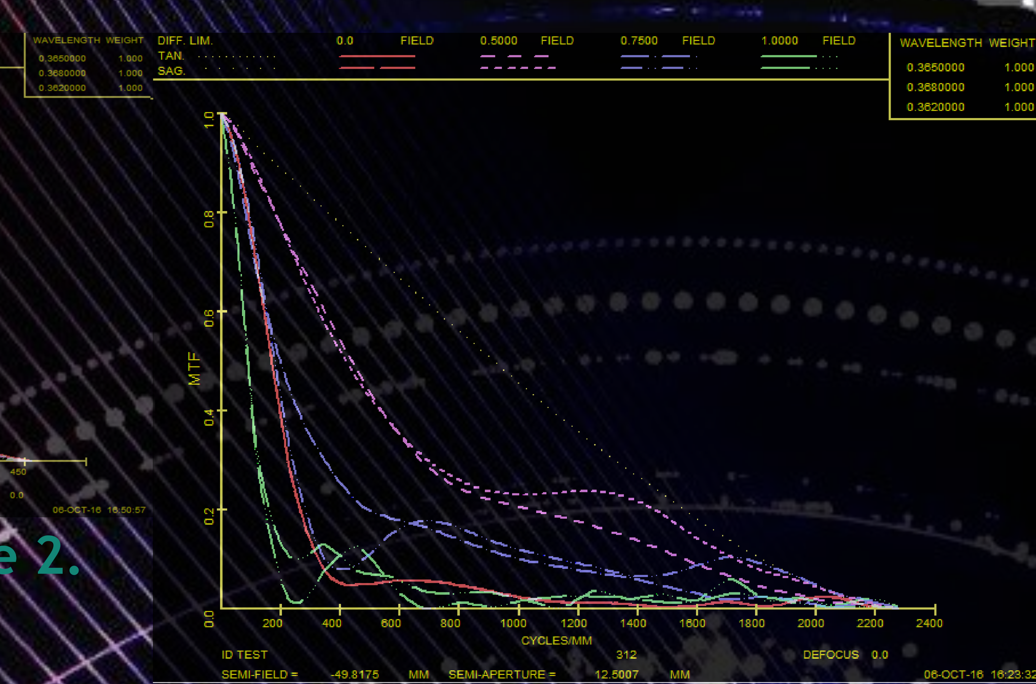

Figure 3.

DESIGN METHOD

A shortcoming of developed method is that we first generate two starting points of photo-objectives in the UV spectrum with maximum of 15 lenses. More in detail, we build macros in Synopsys OSD lens design software and run global search of two separate modules [2].
The most challenging parameters of macro input to be adjusted and determined in macro are: the field of view, a number of lenses, length of objective and glass material. Developed method consist of few steps and stages which should formalize the writing of macro input.
In Step 1, we calculate the characteristics of both parts at object side, field of view and semi-aperture. This is the easier part of adjusting input parameters of macro by assuming a point where the two parts to be connected.

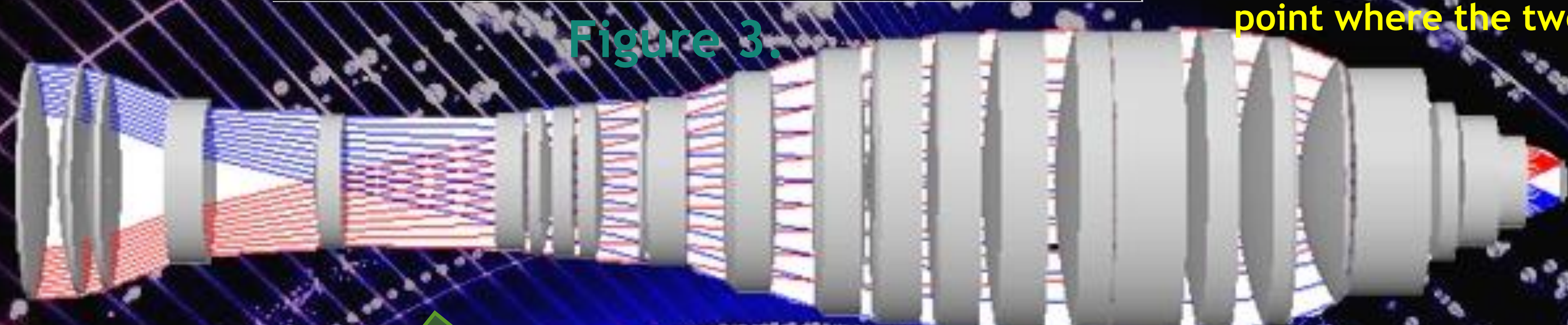

Figure 5.

In Step 2, we run a series of simulations that sweep through the possibilities of starting designs adjusting the number of lenses and total length of optical module. Ideally, these simulations by Design Search should determine a set of input parameters where the transversal aberrations, over entire field, will be less than 0,005 mm.

AEI

Figure 6.

Figure 7.

In Step 3, we combine the separate parts in one optical scheme obtaining the starting point of lithographic objective for further global optimization which tends to provide adequate quality, while maintaining moderate system length and size.

When a design is close to perfect, the glass models have to be replaced by the real glasses from Iline catalog.
There are two ways to replace GLM: manually, or using ARG feature which automatically replaces the glass models [4]. Figure 7 shows the lithographic objective where the Glass models were replaced manually.

ARG

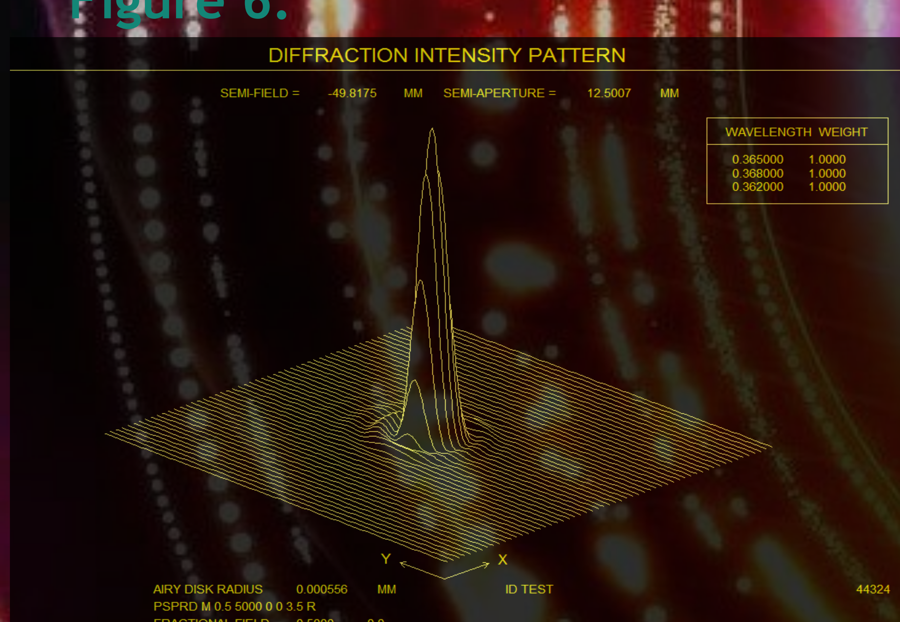

Figure 8.

OPTIMIZATION OF GLASS MODEL

The issue of optimization of the lithographic objectives is probably the most difficult one in the optical system optimization. At present the modern UV lithographic objectives have more than twenty components having aspheric surfaces. That results in more than one hundred optimization variables [5]. Figure 4 shows the MTF of our starting point with glass models having 131 variables. Starting point (Figure 5) with 0,002 transversal abberations was optimized with GNO and GO2 requests, within the merit function up to diffraction - limit. The merit function should consist of GO2 ray grids, the HH at several field points, and GIHT at several points. Within the merit function we limit the region where are iLine glasses available:
CBOUNDS1.88 6.43 1.49 83.55
FBOUNDS 1.92 22.16 1.50 62.67
CUL 1.6 FUL 1.6. The perfect telecentricity in object side is achieved by keeping the telecentric object solve. The telecentricity in image side is controlled by request M 0 600 A P HH 1, within the merit function.

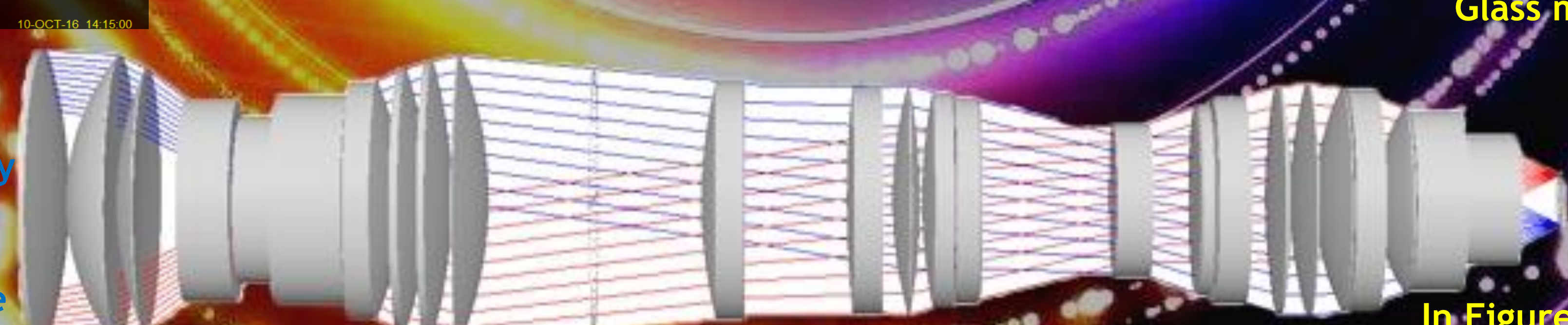

Figure 10.

In Figure 10 is presented UV lithographic objective where the glass models have been replaced by ARG feature. MTF of designed UV lithographic objective can be improved further, by MTF optimization and inserting more lenses.
In Figure 7 is shown UV lithographic objective Improved by inserting one more lens marked by red color.

In Figure 9 is presented the Strehl ratio of designed UV objective (Figure 7) where a glass was replaced manually. In this objective we have inserted one more lens by option for automatic element insertion, AEI 5 1 11 0 10000 .2 50 10 1 5.
Comparing the Strehl ratios we conclude that the UV lithographic objective shown in Figure 11 is our best design. Designed UV lithographic objective having 25 lenses, has total length 680 mm, with distortion 0,001 %. Distribution of diffraction pattern intensity in the half of field is shown in Figure 8. Strehl ratio for 365 nm at the edge of field is 0.998. Simulated internal transmission for 365 nm is 9% without the antireflective coatings.

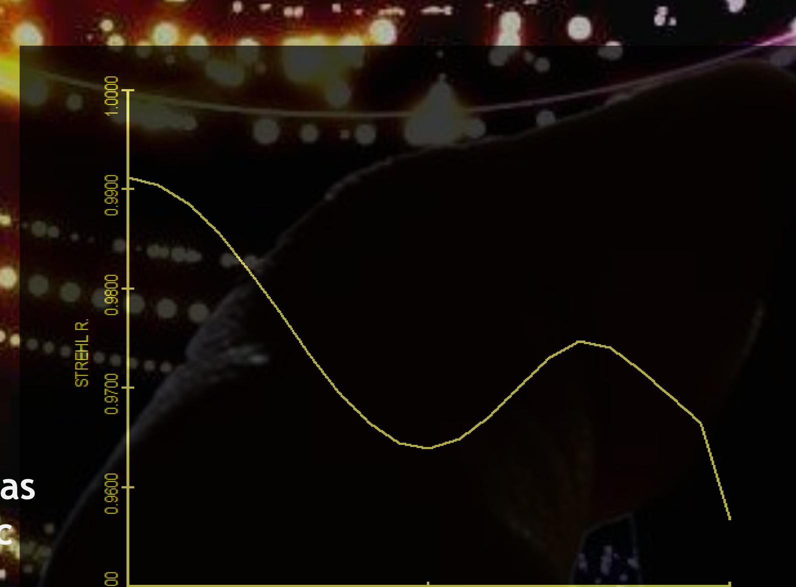

Figure 9.

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