Novel All Reflective Objective Design for VUV Wafer Defect Inspection System

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Abstract – All reflective objective is needed for VUV spectral band (120 nm to 190 nm) wafer defect inspection. A novel all reflective high NA objective design form utilizing reverse Schwarzschild objective is introduced, it achieves an extremely large working distance. A two mirror objective can yield an 80 um field of view (FOV), while a four mirror design can achieve a 600 um FOV.

Keywords: Schwarzschild objective, VUV, all reflective, wafer defect inspection

I. Introduction

A. VUV Spectrum

Shorter wavelength, higher NA is desirable for finer pixel wafer design inspection. WIN is currently working on the next generation bright field broadband inspection tool, the VUV tool, with a spectral band of 120 to 190 nm. Because of the limitation in material selection, all reflective mirror objective is required.

All the designs in this paper have a system NA of 0.9, and the performance is evaluated at 150 nm.

B. KT Tesla Four Mirror Design

During the Tesla development stage, a 4 mirror design was evaluated, as shown in Fig. 1. [1]

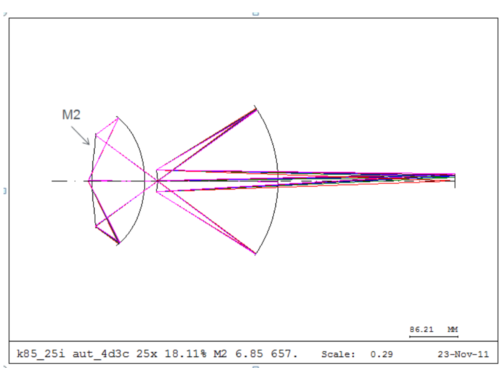

Fig. 1. KT Tesla 4 Mirror Design, 25X

The magnification shown is 25X, which can be easily extended to 900 or more. All four mirrors are aspheric ones. Decent performance is achieved over a relatively large FOV up to 1 mm.

The wafer lies on the left side of the drawing, we will name the mirrors as M1 through M4 by following the light path from the wafer all the way to the sensor, and thus the mirror closest to the wafer is named M2.

In order to minimize the central obscuration on M2, which also limit the system central obscuration, the working distance is relatively small (0.5 mm). M2 needs to be very thin, the mirror diameter over the substrate thickness aspect ratio will be relatively high (>25), as listed in Table 1. M2 is also shaped as a bow to increase the manufacturability. All of these will mean M2 will be very difficult to manufacture and mount, introduces high risk and high cost. Based on that, Tesla project, we decided against the all reflective design.

However, for VUV project, we have no other option but to implement all reflective designs. A better, manufacturable all reflective design form needs to be found.

II. Veyron Objective

A. Schwarzschild Telescope

In 1905, Karl Schwarzschild studied the aplanatic two mirror telescopes, in which both spherical aberration and coma were corrected near optical axis [2]. A picture from the original paper is shown in **Fig.** 2.

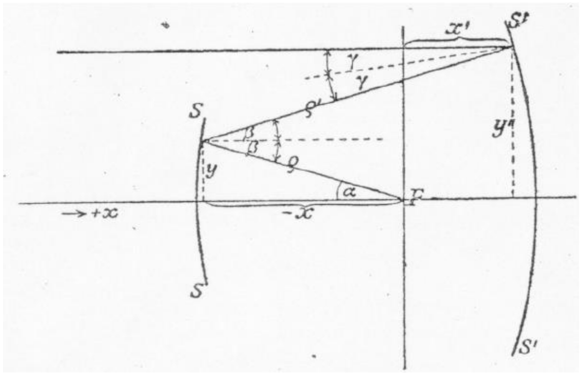

Fig. 2. Schwarzschild Telescope

B. *Schwarzschild Objective*

The original Schwarzschild telescope has the image plane located between the two mirrors, making it inaccessible. Schwarzschild Objective shown in **Fig.** 3 pushes the image outside the two mirror assembly. It utilizes two spherical mirrors, typically concentric to each other, separated by twice the systems focal length; the third order spherical aberration, coma, and astigmatism are all eliminated [3].

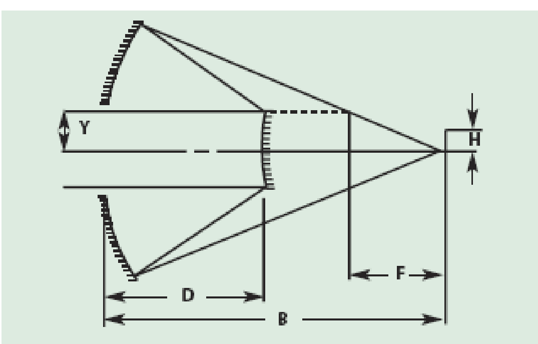

Fig. 3. Schwarzschild Objective.

The short focal length enable the large gap between the smaller mirror and the image plane, which means that we will have very long working distance if we reverse the objective, placing the wafer at the image plane in the above picture.

C. *Veyron Objective*

WIN Tech is currently working on VUV test bench, called Veyron bench, it utilizes a 0.8 NA Schwarzschild objective, as shown in **Fig**, 4. [4]. M1 is an aspheric mirror, while M2 is a spherical one. A FOV of 40 um is achieved, the central obscuration is about 35%, and nominal S.R is better than 80%. Efforts are needed to increase the FOV for 0.9 NA over the VUV spectrum.

The extra long working distance will make it possible for autofocus path and illumination path to be injected from sideways.

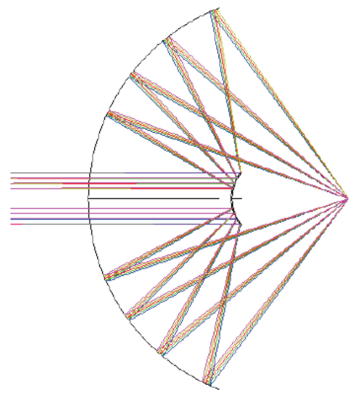

Fig. 4. Veyron Objective

III. 4 Mirror Objective Designs

Several design forms which take advantage of the extremely large working distance of the Schwarzschild objective are studied. The magnification chosen here is 900X.

Because of the limited scope, the tolerance analysis for the four mirror design is not listed. We will concentrate the effort on the two mirror design in the later section.

A. *Coating Performance*

Over the VUV spectrum, the light loss per reflection is about 20 to 25%. **Fig**. 5 shows the performance of various coating designs.

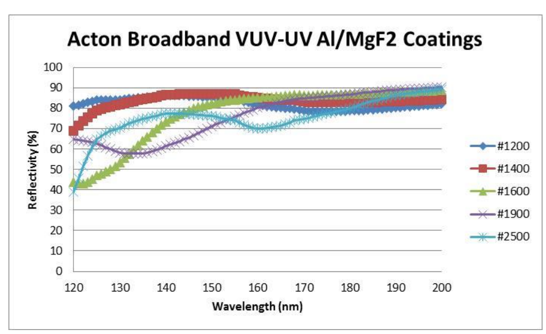

Fig.5. VUV band coating performance.

The heat load on the mirror will require the cooling of the mirror and a limitation of the minimum size of the mirrors. Here, a 20 mm minimum diameter is chosen for easy manufacturability and dissipation of the thermal load. This final minimum mirror size will be determined after careful thermal analysis.

B. 4 Mirror Design Configuration 1

A 4 mirror design is illustrated in **Fig**. 6.

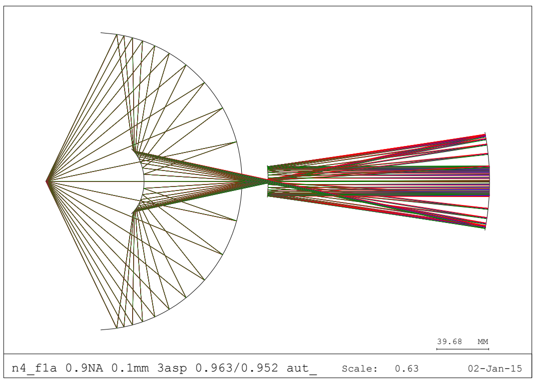

Fig. 6. 4 Mirror Design Configuration 1.

There is an intermediate image lies between M2 and M3, close to the physical location of M4. At least one of M1 or M2 needs to be aspheric to reduce the central obscuration on M4. For this particular design, M1 is spherical, while M2, M3, and M4 are all aspheres. The FOV is about 90 um, the S.R. is 95% to 99%. The system parameters are summarized in Table 2, same as the parameters of all other designs in this paper.

One fact need to be mentioned is that for a 900X design, the NA at the TDI sensor side is 0.001. For a 20 mm diameter M4, the distance from M4 to the sensor will be 10 meters! It is no surprising that the overall length from the wafer to the sensor is 11.3 meters in this design. The limiting system obscuration occurs at M2, which is about 0.294.

Ideally, when designing any optics, we would like to gradually reduce the NA of the system for easier aberration control. However, for the Schwarzschild objective, instead of reducing the NA after M1, the NA actually increased for M2, which making the decentering and tilting tolerance of M2 relative with M1 to be quite tight. Study shows that a 0.1 um decenter is required, which is quite achievable.

The working distance is tens of millimeters, and the mirror substrate can be as thick as necessary for M2. The system is quite manufacturable. We believe that the increased working distance, which enables the increase of the mirror substrate thickness and manufacturability, can offset the increase in the alignment sensitivities,

Sure we would like to reduce the ray bending on M2, this will lead to the next design form.

C. 4 Mirror Design Configuration 2

A less sensitive design configuration is shown in **Fig.** 7. Instead of having the intermediate image between M2 and M3, the intermediate lies between M3 and M4; the reduced ray bending on M2 making the sensitivities on M2 to be more relaxed.

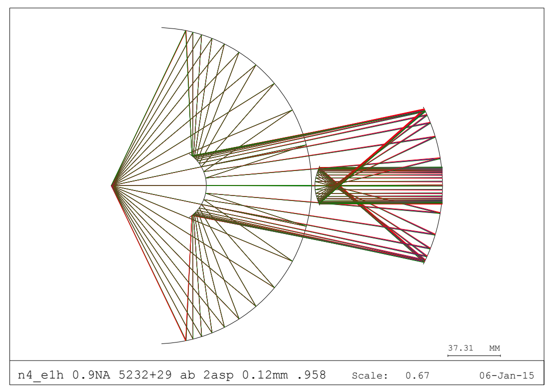

Fig. 7. 4 Mirror Design Configuration 2.

In addition, it is not necessary to correct for the aberration at the intermediate image anymore, a better overall aberration correction can be achieved. In the listed design, M1 and M2 are spherical mirrors, only M3 and M4 are aspheres, The FOV is even larger, about 120 um, with a S.R. between 0.948 to 0.974. The central obscuration is about 0.294.

D. 4 Mirror Design Configuration 3

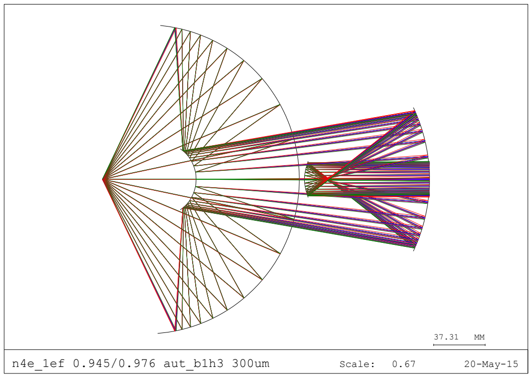

Fig. 8. 4 Mirror Design Configuration 3.

It might be interesting to push the limit to see what is the largest possible FOV can be achieved when using 4 aspheres. **Fig.** 8 shows such an effort.

The FOV can be pushed to 600 um, while the central obscuration is increased slightly to 0.301, the S.R. varies from 0.96 to 0.97.

IV. 2 Mirror Objective Design

A. Required Lamp Power

The relationship between the require lamp power, the Objective FOV and system throughput is illustrated in **Fig**, 9. It assumes a reflection loss of 25% per mirror.

From the graph, we can see that if a 1 wafer per hour throughput is desirable, then 4 mirror design is required. Sadly, the lamp power needed is also prohibitively high. For lower throughput, an 80 um or so FOV might be more desirable.

B. Two Mirror 0.9 NA Design

As mentioned before, the 0.8 NA Veyron objective utilizes an aspheric M1, and a spherical M2. It is essential to implement two aspheric mirror design to achieve a 0.9 NA design, Fig. 10 shows such a design with an 80 um FOV for 0.9 NA.

This design has a magnification of 1000X. A S.R. of 0.951 at edge and 0.975 on axis can be achieved. The central obscuration is about 0.216. The size of M2 is made to be 26 mm for better manufacturability and thermal management.

Basic tolerance study is listed in **Table** 3. All the tolerance is achievable, similar to the Veyron objective tolerance.

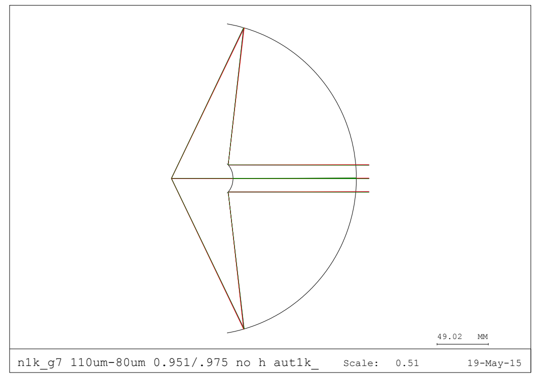

Fig. 10. All Aspheric Two Mirror 80 um Design.

	M1	M2	
Surface Figure	0.1/0.03	0.3/0.03	@546.1 nm
DLR	0.00005	0.0005	
Mirror Tilt (urad)	1	3	
Mirror Decenter (um)	0.1	0.1	
Compensator change, M1/M2 gap (um)	1.1		

Table. 3. Typical 2 Mirror design tolerance table

A toleranced S.R. of 83% can be achieved. Tighter tolerances, or using additional compensator can also improve the final performance. For example, by adjusting the tilt between the two mirrors, the toleranced S.R. can be better than 89%.

For the four mirror design, similar tolerance will be sufficient.

More efforts are needed to work with the vendors to improve the design to make it more manufacturable and improve the performance.

	M2 to Wafer Distance (mm)	Sag (mm)	Working Distance (mm)	Diameter (mm)	Substrate Thickness (mm)	Total Thickness (mm)	Diameter over Thickness Ratio
K85_25i center	6.85		0.5	162.33	6.35	6.35	25.6
K85_25i edge	6.85	6.16	0.5	162.33	6.35	12.51	13.0

Table. 1. KT Tesla 4 Mirror design M2 aspect ratio.

						Mirror Size (mm)				Obscuration			
Description	# Mirrors	# Aspheres	FOV (um)	S.R.	OAL (mm)	M1	M2	M3	M4	M1	M2	M3	M4
4M, Config 1	4	3	90	0.95-0.99	11299	223	46	71	22	0.035	0.294	0.2	0.141
4M, Config 2	4	2	120	0.948-0.974	13000	219	42	106	25.74	0.265	0.294	0.141	0.223
4M, Config 3	4	4	600	0.958-0.971	11267	241	46	157	22	0.28	0.301	0.141	0.189
2M, Aspheric	2	2	80	0.951-0.975	14381	286	26			0.076	0.216		

Table. 2. Design Parameter Comparison.

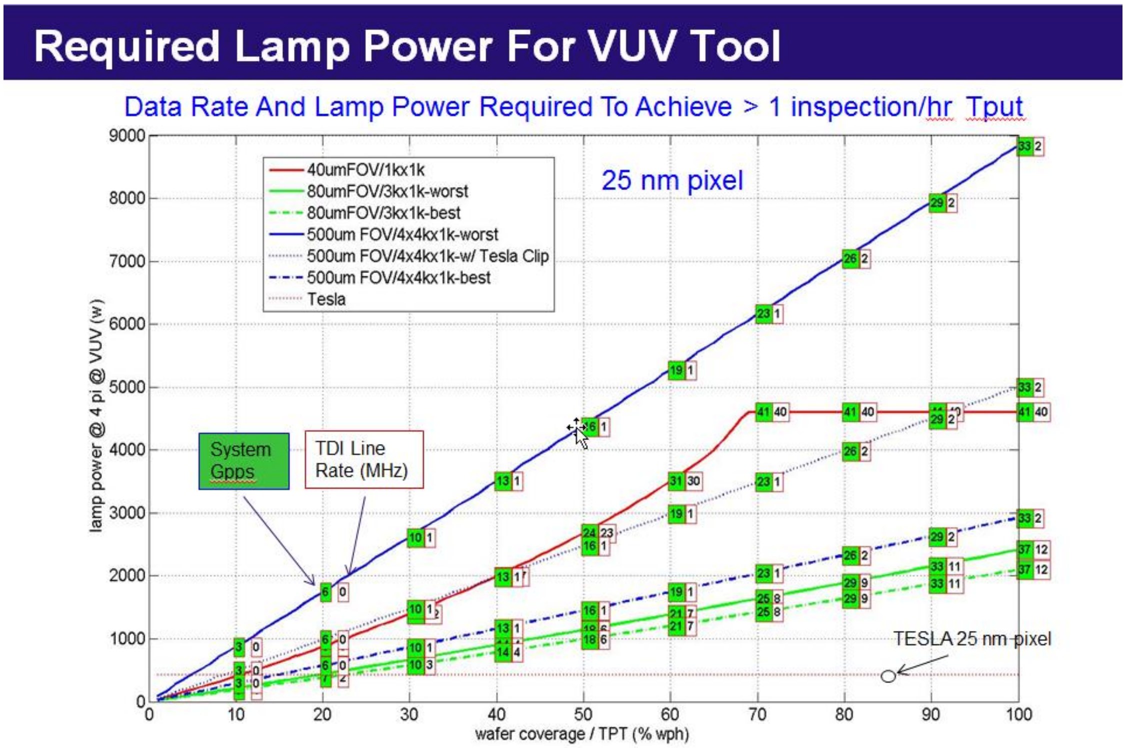

Fig. 9. Required Lamp Power for VUV Tool.

V. Conclusion

A novel all reflective optical design utilizing Schwarzschild objective for the VUV project is explored. For 4 mirror design, a FOV of 600 um is achievable, while for a 2 mirror design, an 80 um FOV can be achieved. The major advantage of this design form is extremely long working distance can be achieved, this will make the system to be manufactrable, and make it possible to inject AF and illumination from sideways.

Acknowledgment

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