High Uniformity Design of UV LED Illuminators for Exposure Equipment

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Abstract: We have presented the optical system design of control uniformity illumination system for stepper lithography. The illumination system acted a key factor in the lithography, because the output light source quality affected the exposure resolution and yield rate of products. The illumination system was composed by seven lens, imaging field was 12.6mm, chief ray angle was less than 0.4 degrees, distortion was less than 0.47% and numerical aperture was 0.1644. the irradiance flux of target area average was about 20 mW/cm^2. The system's uniformity deviation was less than ± 3 percentages. Each UV-LED of illumination system was individually controlled. It could make the imaging plane always have high uniformity to overcome the problem of light source attenuation.

1 INTRODUCTION

Currently, the integration circuit was rapidly developing to high density and high productivity by the lithography, pattern transfer and process technology. While early integration circuits features were 25mm, currently manufactured features were less than 20 nm. The integration circuits of feature size, separation of structures and layer-to-layer registration were decreased by approximately 30% linearly per generation and doubling of the density of transistors each generation (Moore, 1998). It has become what we know as "Moore's Law."

The exposure process was the most important technology in the integration circuit fabrication. It could directly affect the size of integrated circuits, wafer utilization and productivity. Lithography equipment usually composed by the illumination system, projection lens system and movement platform and it was used for exposure process (Rueggeberg and Caughman et al., 1994). The illumination system used to modify the light source meted the request of numerical aperture, illumination field and uniformity etc. The illumination system output light source illuminated on the reticle and the reticle pattern transfer to the wafer by projection lens system. The illumination system acted a key factor in the lithography, because the output light source quality affected the exposure resolution and yield rate of products. In the industry, the common lithography equipment was proximity mask aligner. It had the advantages of large area exposure and simple device structure etc. In the 2010 years, Reinhard Voelkel team created an illumination system which had two microlens-based Köhler integrators. The Light source output was telecentric and high uniformity. The system resolution was 10um (Voelkel and Vogler et al., 2010). In the 2010 years, S. Partel team created a new illumination system for SUSS mask aligner using two consequent optical integrators and an exchangeable illumination filter plate. The filter plate could reduce the interference effected to increase the system resolution. The system resolution is 2um (Partel and Zoppel et al., 2010). However, the proximity mask aligner system resolution closed to

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the nanometer, this kind of lithography structure was not valid for mass production and a single defect already made a complete microchip unusable.

For this reason, many people turned to research step lithography systems. It had the advantage of the higher resolution, low cost of reticle and easy to mass production. In the 1986 years, Victor Pol team presented a stepper lithography which light source was KrF excimer laser (248nm). The lighting system had the numerical aperture of 0.38 and the imaging field greater than 14.5 mm. The system resolution was 0.8um (Pol and Bennewitz et al., 1986). In the 2008, Rosanne M. Guijt team presented a low cost UV-LED lithography which used a pinhole and a small plastic tube and focused using a microscope objective onto a substrate for direct lithographic patterning of the photoresist. The system resolution was higher than 20 µm (Guijt and Breadmore, 2008). In the 2016 years, Hans-Christoph Eckstein teams presented a UV LED lithography which could be demagnified five to one hundred times and position accuracy was higher than 100 nm (Eckstein and Zeitner et al., 2016). In the prior art, people created lithography illumination system by mercury lamp, LED or laser. When used for long periods of time, these light sources attenuated to affect output uniformity and flux. It declined the yield rate of product.

Therefore, in the studying, we presented a control uniformity illumination system for stepper lithography. Each UV-LED of illumination system was individually controlled. It could make the imaging plane always have high uniformity to overcome the problem of light source attenuation. The illumination system composed by UV-LED, reflector, REMA lens system and light source controller. The UV-LED emission light intensity distribution was changed by the reflector and coupled to the projection lens system. The REMA lens system organized the input ray to be user defined light intensity distribution and illumination field size. The controller was used to control each UV-LED output efficiency made the imaging plane always has high uniformity.

2 THE OPTICAL DESIGN OF ILLUMINATION SYSTEM

Lithography is the key equipment in the integrated circuit process and its' Illumination quality was the most important factor. It directly affected the size of integrated circuit line per. There are three important factors in the lithography illumination system (Weichelt and Bourgin et al., 2017):

- NA: The illumination system NA should correspond with the project lens system, otherwise the resolution of the projection system will decrease.
- Uniformity: It effects the exposure depth of the lines. The uniformity deviation usually lower than 10%.
- Efficiency: It effects the system conversion efficiency.

The illumination system was designed by the sequential optical simulation software(Zemax) and non-sequential optical simulation software(FRED). The sequential optical simulation software was used to optimize the imaging plane uniformity and third aberration. The non-sequential optical simulation software used to eliminate the effects of stray ray. The list of design goals was as follows:

1. Imaging plane numerical aperture 0.165
2. Imaging plane uniformity deviation < ± 4 %
3. Imaging plane irradiance > 15 mW/cm^2
4. Imaging plane size > 20 x 8 mm^2
5. Chief ray angle < 0.5 degrees
6. Distortion < 0.5 %

Figure 1: The UV-LED array arrangement.

The first step for design the illumination system was to determine the light source parameters. When the UV-LED(LTPL-C034UVH365) inputted 5V and 700mA, the UV-LED luminous flux was 720-860mW. If the imaging plane irradiance should higher than 15mW/ cm^2, the UV-LED needed 5 x 5 chips array at least. In order to increase the utilization rate of light source, the chips array coupled with a reflector made the half of diverge angle of light source less than 10 degrees, reference the Fig.1. The REMA lens system was arranged behind the UV-LED chips array. The REMA lens system was designed by Köhler illumination (Köhler, 1893). Köhler illumination proposed by August Köhler for optical microscope illumination, allows to adjust the size and the numerical aperture of the object illumination in a microscope independent from each other. Köhler illumination provides uniform illumination of the object plane independent of shape, extension and angular field of the light source.

2.1 Optical Design of REMA Lens System

The lens system was designed by sequential and non-sequential optical simulation software. The sequential optical simulation software was used to design the light path, optimize third aberrations and assemble tolerance. The non-sequential optical simulation software was used to analysis and eliminate stray ray effects. Though these optical simulation, the simulation results were more close to the fabrication production.

2.1.1 Sequential Optical Simulation

In the optical simulation, the light source size was 30*30mm and half of divergence angle was 10 degrees. In order to reduce production price and error, the lens radius and diameter should not exceed 500mm and 90mm, and the front and back radius of each lens should differ by more than 10%. After the design, the lens system was composed by seven lens, imaging field was 15.6mm, chief ray angle was less than 0.4 degrees, distortion was less than 0.47% and numerical aperture was 0.1644. The data referred to the Fig.2. and Table. 1.

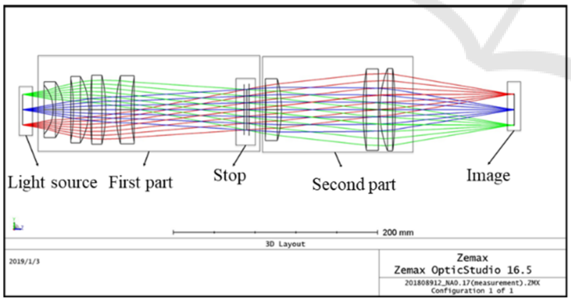


Figure 2: Optical light path diagram.

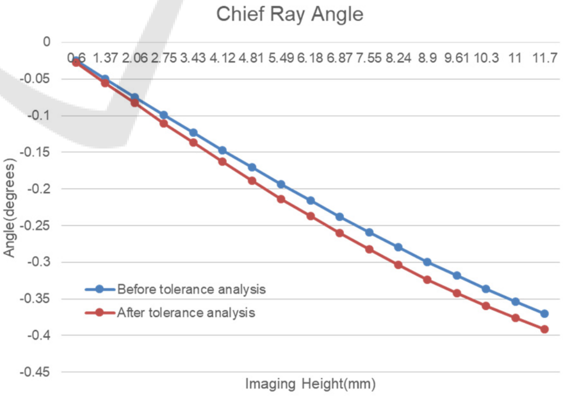
Table 1: The Lens data of the REMA lens system.

Items	Radius	Thickness	Material	Semi-Diameter
Lens1	-37.11	9.9	Fused-silica	20
	-53.11	10		23
Lens2	-176.73	15	Fused-silica	26
	-68.52	1.5		28
Lens3	388.68	15.045	Fused-silica	29
	-154.86	10		29
Lens4	127.985	15.035	Fused-silica	29
	183.01	113		28
Stop		19		20.1
Lens5	-482.48	15.035	Fused-silica	24
	-117.9	80		26
Lens6	246.599	14.9	Fused-silica	36
	Inifinity	1.5		36
Lens7	112.551	15.105	Fused-silica	36
	-323.880	116.6		36
Image				15.685

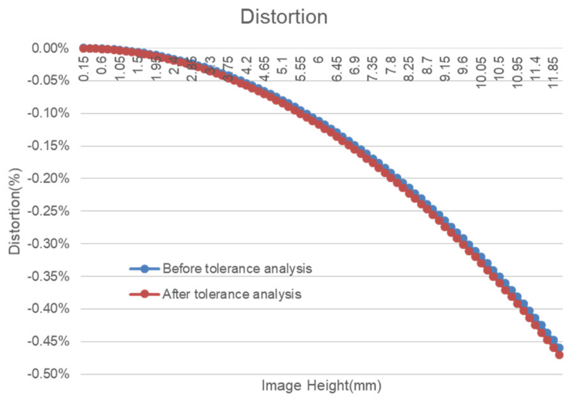
The simulation results of REMA lens system meted the goal, the next step was doing tolerance analysis. The tolerance analysis had two parts that were lens manufacturing tolerance analysis and lens system assemble tolerance analysis. The tolerance analysis data referred to the Table. 2. After the tolerance analysis, the simulation results still comply with the target, referred the Fig. 3.

Table 2: Tolerance analysis data.

Tolerance Parameters(wavelength: 365nm)		
Itesms	surface Tolerances	Element Tolerances
Radius	0.00%	non
Thickness	0.1mm	non
DecenterX	0.3mm	0.1mm
DecenterY	0.3mm	0.1mm
Tilt X	0.3 degrees	0.1degrees
Tilt Y	0.3degress	0.1degress



(a)



(b)

Figure 3: Third aberration data. (a).Chief ray angle diagram. (b). Distortion diagram.

2.1.2 Non-sequential Optical Simulation

The targets of uniformity and irradiance was simulated by non-sequential optical simulation software. From the simulation results, the irradiance flux of target area average was about 20 mW/cm^2. The system's uniformity deviation was less than ± 3 percentages. It proves that the stray ray effect was very low, the irradiance distribution referred Fig. 4.

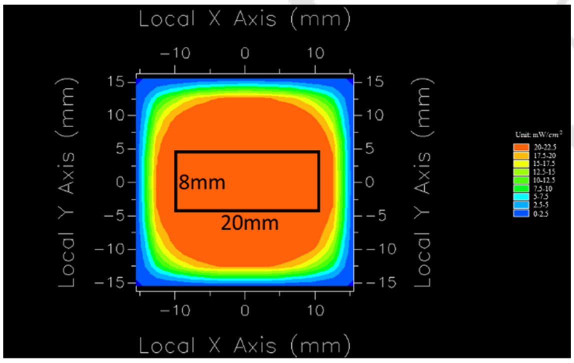


Figure 4: The REMA lens output irradiance map.

3 DISCUSSION

In the studying, we presented a control uniformity illumination system for stepper lithography. The system had the 25 UV-LED. Each UV-LED could individually control the output flux and the light source switching frequency was less than 20 ms to avoid flicker effect. The REMA lens system was design by sequential and non-sequential optical simulation software. After the tolerance analysis, the simulation results still meted the targets.

4 CONCLUSION

We have presented the optical system design of control uniformity illumination system for stepper lithography. The lens system was composed by seven lens, imaging field was 15.6mm, chief ray angle was less than 0.4 degrees, distortion was less than 0.47% and numerical aperture was 0.1644. The irradiance flux of target area average was about 20 mW/cm2. The system's uniformity deviation was less than ± 3 percentages. In the future, we could add an intelligent uniformity control algorithm and auto irradiance measurement system. The irradiance measurement system used to capture each point irradiance on the imaging plane, and the data transferred to controller. The controller controlled UV-LED flux by the algorithm that make the imaging plane always have high uniformity.

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