

UV LED ILLUMINATION STEPPER OFFERS HIGH PERFORMANCE AND LOW COST OF OWNERSHIP

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ABSTRACT

Flat panel displays (FPD) are electronic viewing technologies used to let people see content in media and entertainment, consumer electronics, personal computer and mobile devices. Other applications and industries are medical, transportation and industrial equipment. FPD is often the preferred choice due to lower weight and less power consumption. Common types of FPD are liquid crystal display (LCD), plasma display panels (PDP) and organic light-emitting diode (OLED).

The global market for FPD continues to grow due to the high demand in the automobile and smartphone industries. As a result of the high demand, the FPD manufacturing industry continues to remain highly competitive. In this cost sensitive arena, FPD manufacturers need to find new ways to reduce the cost of ownership of lithography equipment.

Most lithography systems in FPD manufacturing plants use high power mercury ARC lamps to generate i-line (365nm) wavelength for the photoresist exposure process. This is a costly process as the mercury ARC lamps have a limited lifetime, typically less than one month, which results in downtime to swap lamps.. The cost of replacing the high power mercury ARC lamp, together with the high electricity consumption, and disposal of mercury waste, turns out to be a substantial operating cost.

This paper will demonstrate how the use of ultraviolet light emitting diode (UV LED), in replacing the high power mercury lamp, will reduce the overall operating cost which therefore lowers the cost of ownership of the stepper. The breakdown of cost structure will be discussed in detail and show that UV LED is a good replacement solution for the high power mercury ARC lamp.

The throughput improvement by using UV LED will also be discussed and compared to the conventional high power mercury arc lamp. The analysis will also show that the consistency of throughput, as compared to the degradation of mercury arc lamp intensity, as

well as the time saved for replacement further reduces operating costs.

This paper also demonstrates the improved performance of dose accuracy and repeatability, as well as the capability to achieve extremely low exposure doses without compromising dose accuracy. The improvement in stepper reliability by removing the conventional shutter moving parts will also be discussed.

The performance data for illumination intensity, dose accuracy, uniformity, spectral line width, CD uniformity and cost reduction will be discussed in detail. The final analysis will show that moving to UV LED illumination offers lower cost and better performance.

Key words:

Flat Panel Display, UV LED, Dose accuracy, Energy Efficiency, CD uniformity

I. INTRODUCTION

The presence of light is the most essential energy needed to trigger a chemical reaction of the light sensitive chemical, often called a photoresist, to form a circuitry pattern on a substrate for a projection photolithography stepper. A major drawback of photochemistry is the inability of most molecules to absorb and react to visible light efficiently, leading to the use of ultraviolet radiation. Although daylight is the most natural source of ultraviolet radiation, it is complex to control accurately and reliably in most industries. For many years, artificial white light, such as the high power mercury lamp, has been used in most lithography processes. Given its inefficiency, since only certain specific wavelength ranges are relevant and used to trigger a photochemical reaction, the rest of the spectrum, which is also a source of energy, were considered a waste energy. This has a high impact on cost efficiency for such high energy wastage. The switch to UV LED would greatly improve the cost efficiency, and at the same time, not compromise the tool performance.

II. STRUCTURE OF UV LED SOURCE AND STEPPER INTEGRATION

The UV LED housing structure is in a compact form of 16 inches in diameter and 14 inches in length. The optical head consists of a dense array of 365nm UV LEDs. Cooling liquid was used to maintain the temperature of the optical head. (Figure 1).

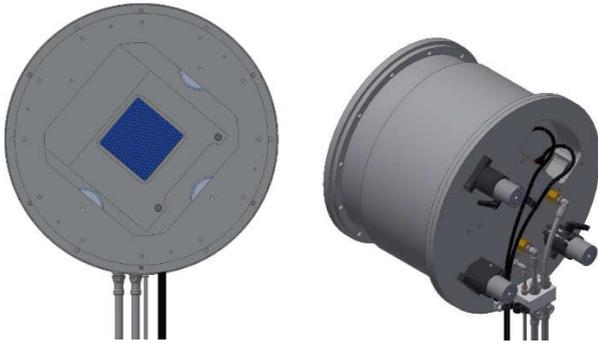


Figure 1

The lithography stepper employed in this study is a Rudolph Technologies JetStep® G45 System. The system is a Gen 4.5 flat panel display stepper that utilized a 10KW mercury lamp as its exposure light source. The system's lens, with a 0.15 numerical aperture (NA) provides a large depth of focus (DOF) to maintain image integrity and CD control at 1.5 μ m. The system has the capability to provide i-line (365 nm) wavelengths with intensity of 200mW/cm².

III. TEST AND PERFORMANCE RESULTS OF LED SOURCE

A. Resolution and Depth Of Focus

Test Description

Image resolution is determined by imaging features in photoresist, measuring the features, and analyzing the data to determine the line/space, CD control and depth of focus (DOF) at nine positions in the lens field.

The test uses a Rudolph resolution test reticle that has test features for characterizing the image resolution. The features, matching the specified resolution of the lens, are imaged on a resist-coated substrate in a focus/exposure array. The resolution test patterns contain line/spaces and contacts/holes.

Each focus/exposure array consists of five rows for exposure dose and 17 columns using 2.0 μ m focus increments and dose increments \pm 10% in 5% increments. This provides sufficient data to evaluate the best exposure dose for the process and determine the depth of focus at the specified resolution.

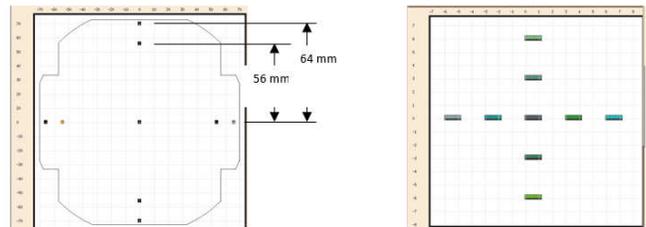


Figure 2

Nine (9) sites in the lens field are displayed in Figure 2 (Resolution Test Pattern Lens Field Map) are evaluated. Each array is positioned on the substrate to correspond to the field position of the lens. The resulting test job layout is in Figure 2 (Resolution Test Job Layout).

After exposing and developing the plate, the images are inspected using an optical microscope and a scanning electron microscope (SEM). Figure 3 shows a focus exposure array as seen on the SEM.

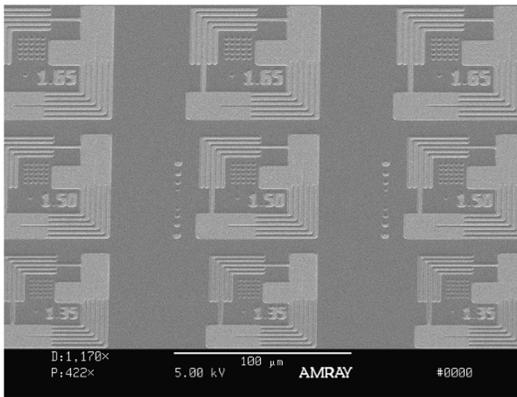


Figure 3

Figure 4 shows measurement of a 1.5µm line by the SEM measurement system.

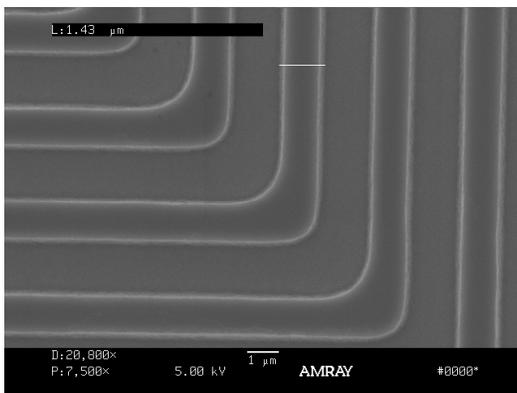


Figure 4

Test Result

Figure 5 shows the results of the focus exposure matrix across the full field of the lens. A common corridor across the entire field of 10µm was achieved for 1.5µm lines and spaces.

Die Position	Focus Position (µm)																
	-16.0	-14.0	-12.0	-10.0	-8.0	-6.0	-4.0	-2.0	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
T (H)						1.470	1.450	1.450	1.450	1.470	1.470						
T (V)						1.450	1.431	1.450	1.431	1.411	1.431						
TZ (H)						1.489	1.489	1.489	1.489	1.489	1.489						
TZ (V)						1.470	1.470	1.470	1.450	1.470	1.470						
AXIS (H)						1.489	1.470	1.489	1.470	1.489	1.489						
AXIS (V)						1.450	1.450	1.450	1.470	1.470	1.489						
BZ (H)						1.470	1.470	1.489	1.489	1.489	1.489						
BZ (V)						1.489	1.470	1.470	1.470	1.470	1.489						
BH (H)						1.489	1.489	1.489	1.489	1.470	1.489						
BH (V)						1.470	1.489	1.470	1.470	1.470	1.470						
R (H)						1.529	1.529	1.529	1.529	1.509	1.529						
R (V)						1.529	1.509	1.529	1.529	1.489	1.509						
RZ (H)						1.529	1.529	1.529	1.529	1.548	1.568						
RZ (V)						1.529	1.529	1.529	1.529	1.529	1.568						
LZ (H)						1.509	1.509	1.529	1.548	1.529	1.548						
LZ (V)						1.509	1.509	1.509	1.529	1.509	1.529						
L (H)						1.529	1.509	1.509	1.529	1.529	1.548						
L (V)						1.509	1.509	1.470	1.470	1.489	1.489						

Figure 5

B. Lens Distortion

Test Description

The purpose of this test is to verify that the projected image distortion (PID) errors are within acceptable tolerances for good inter-field image positioning.

The camera setup test measures the actual projected image location against the expected location and generates an error vector plot from the X and Y differences. The metrology sensor package in the stage is used to map the aerial image of the calibration reticle. The 33 positions in the lens field are measured; each position is measured three times.

Figure 6 displays the locations on the reticle of the 33 point measurements in red.

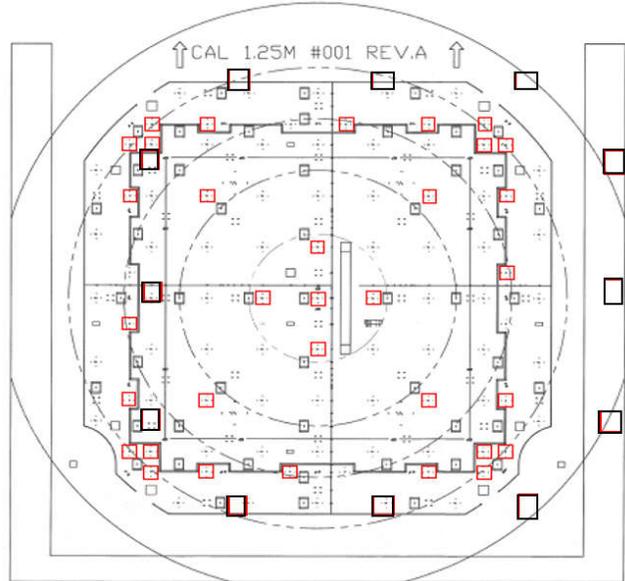


Figure 6

Test Result

Figure 7 shows the results of all 33 measurement points which were within the target of 0.25µm. The radius of each circle was set at 0.5µm and the max vector was measured at 0.19µm.

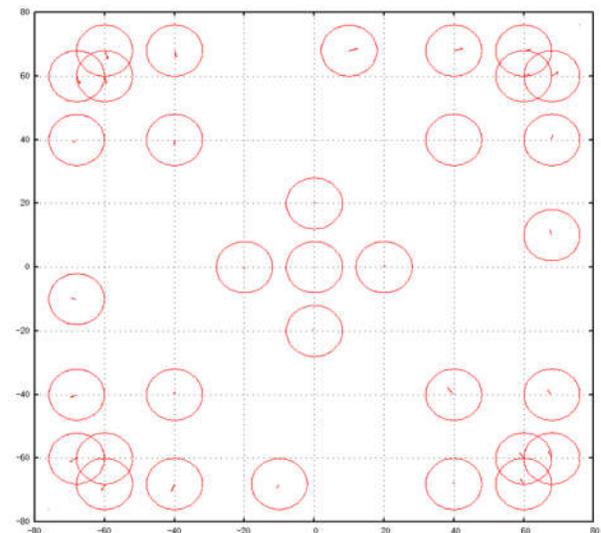


Figure 7

C. Exposure power and dose accuracy

Test Description

The purpose of this is to verify that the exposure power at the image plane is within acceptable limits. The dose accuracy and repeatability were tested to ensure that the dose is delivered at the image plane within acceptable limits for 50, 100 and 150mJ doses.

Both tests used the OAI radiometer and a 365nm probe on the stage.

Test Result

Exposure Power

Filter @ 6nm wavelength Power @ 167mW/cm²

Dose Accuracy

	32mj to 64mj	64mj and above
Max Power (1 amp)	1%	0.5%

	2mj to 8mj	8mj and above
Min Power (120m Amp)	1%	0.5%

D. Illumination Uniformity Test

Test Description

This test verifies that the illumination non-uniformity is within system specification.

The uniformity sensor on the metrology sensor package (MSP) is stepped throughout the usable lens field in a 13 X 13 array at a 16.25mm pitch. Data points outside the illuminated region are discarded during the analysis.

Test Result

The test result in Figure 8 show that the illumination uniformity was within the specification of 3%, reading at 2.8%.

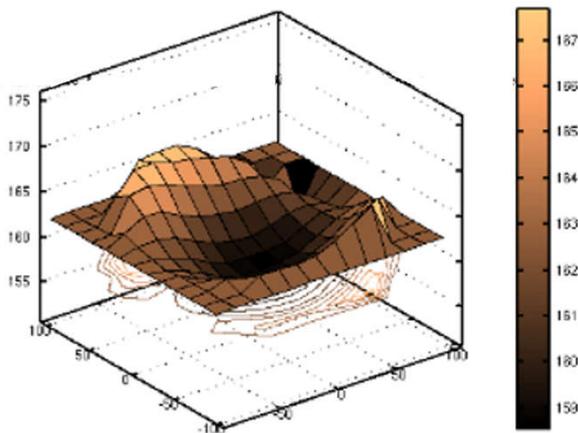


Figure 8

E. Illumination Spectrum

Test Description

The purpose of this test is to quantify the illumination spectrum bandwidth.

The Ocean Optics HR4000+ Spectrometer was used and setup near the uniformity sensor on the MSP and stepped throughout the usable lens field in a 13 X 13 array at a 16.25mm pitch. Data points outside the illuminated region are discarded during the analysis.

Test Result

The result shows (Figure 9) that the bandwidth was expected at 365nm for i-line wavelength.

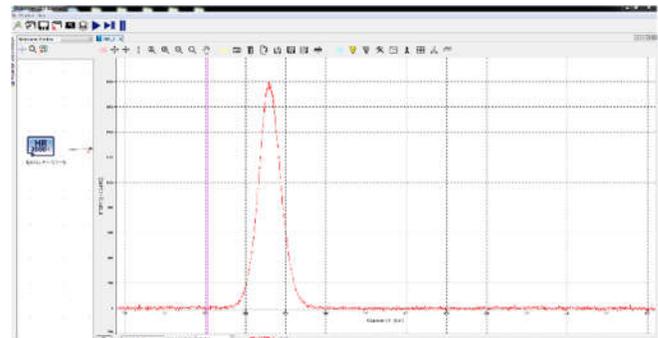


Figure 9

IV. Value of Ownership

The UV LED light source significantly increases the value of ownership for the stepper and provides high return on investment through significantly lower operating costs and better throughput, which will be discussed in detail.

A. Low Operating Cost

Lower operating cost is driven by several key factors, including reduced energy requirements and less scheduled downtime on the stepper.

Energy reduction is often overlooked, but is a key factor in lowering operating costs. The UV LED uses approximately one third the energy to excite the light source than the mercury lamp. It is clearly understood that UV LED generates less heat waste than a mercury lamp, adding the benefit of reducing the cooling required for the heat waste. The full reduction of exhaust air, from 5000cfm or 14m³ per min to none, is a significant improvement in cost saving.

In addition, cleanroom facilities such as air and water supply would be needed for the mercury lamp housing unit in order to maintain the correct temperature. By switching to an UV LED illuminator, the water usage for cooling purposes was reduced by 40%.

Elimination of the regularly-scheduled lamp replacement downtime increases tool throughput and productivity. Through the removal of the high power mercury lamp, which required periodical replacement every 1000 hours, lamp cost is removed along with the corresponding energy consumption of more than 21,000 KWhrs per month. At the same time, it removed the need to halt the stepper for lamp replacement work, thus further improving tool utilization and productivity.

B. Throughput Improvement

Although the power output of the UV LED light source is similar to that of the mercury arc lamp, the UV LED source actually delivers higher and more stable productivity to the system.

Due to the constant output power of the UV LED, as compared to the mercury lamp whose intensity degraded over time, the stepper throughput could be kept constant, which is an improvement from the mercury lamp performance.

The switch to UV LED would also mean the removal of the mechanical exposure shutter, thus improving the reliability of the stepper. With the electronically-controlled UV LED switch, the exposure time could be further reduced without compromising dose stability, adding another advantage to the stepper throughput.

C. ROI Analysis

With the estimated operating cost and the improvement in throughput, ROI can be analyzed as shown below:

Using typical display layers of 90 exposure sites at 30mj/cm² and with production improvement only, the ROI of UV LED can be achieved in less than 13 weeks. (Figure 10)

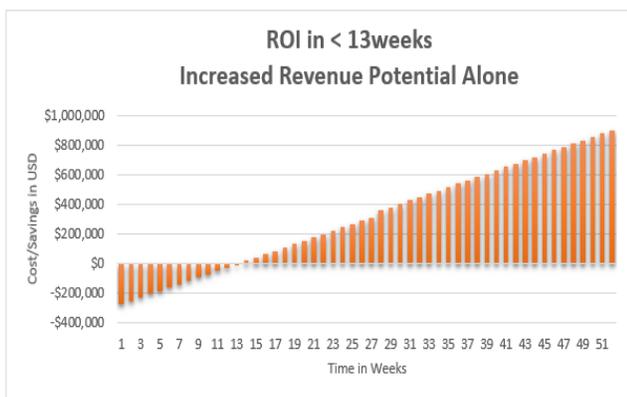


Figure 10

Using typical display layers of 90 exposure sites at 30mj/cm² and with production improvement and cost reduction, the ROI of UV LED can be achieved in nine weeks. (Figure 11)



Figure 11

The ROI analysis was extended to include operating cost as shown in Figure 12.

RUDOLPH TECHNOLOGIES		Process. Control. Yield.	
JETSTEP LED Illuminator			
	10kW Lamp	LED Illuminator	
Price per Substrate	\$ 1,500		
Number of Layers	12		
Hours per day	24	24	
Utilization	80%	80%	
Substrate Tact Time (30 Shots at 100mj/cm ²)	71.3	69.7	
Complete Substrates layers per day	969	992	
Complete Substrates layers per Month	29,471	30,147	
Delta Improvement in Revenue per Month		\$ 84,564	
Down time for Lamp Change (in hours)	3	n/a	
Down time per year (in hours)	26	n/a	
Lost Output per year	1,327	n/a	
Down Time-Caused Lost Output per month	\$ (13,822)		
Lamp Life time (in hrs)	1,000	n/a	
# of Lamps per year	9	n/a	
Lamp Cost	\$ (11,500)	n/a	
Lamp Cost per year	\$ (100,740)	n/a	
Lamp Cost Per Month	\$ (8,395)		
Electric Rate per kWhr	0.074	\$ 0.074	
Electric Usage per Month	-22472	-858	
CDA Rate/CFM	6.7	\$ 6.70	
CDA Reduction	-5000	0	
Operation costs per month	\$ (35,163)	\$ (63)	
Total Increased Revenue Potential for LED illuminator per month		\$ 98,386	
Total Savings for LED illuminator per month		\$ 43,494	
	Total	\$ 141,880	

Figure 12

With the life span of greater than six months and ROI of less than nine weeks, the ROI analysis has demonstrated the long-term cost saving benefit of using a UV LED illuminator.

In addition to ROI analysis, a comparison of the relative operating cost between high power mercury lamp and UV LED and the savings for using UV LED are shown in Figure 13.

	10kW Lamps			Cost
	Unit	Units/Yr	Rate	\$/Year
Lamps	lamp	9	8000	72000
Electricity	kWh / yr	269,808	0.074	19979
Exhaust Air	CFM	5000	6.7	33333
Lamp Disposal	lamp	9	200	1800
Total				\$ 127,112

	UVLED			Cost
	Unit	Units/Yr	Rate	\$\$/Year
Lamps		0	0	0
Electricity	kWhr	10,302	0.074	763
Exhaust Air	NA	0	0	0
Lamp Disposal	NA	0	0	0
Total				\$ 763

	Savings/Yr	Savings/Mo
Lamps	\$ 72,000	\$ 6,000
Electricity	\$ 19,216	\$ 1,601
Exhaust Air	\$ 33,333	\$ 2,778
Lamp Disposal	\$ 1,800	\$ 150
Total	\$ 126,349	\$ 10,529
	per Year	per Month

Figure 13.

With a UV LED illuminator, the operating cost was significantly reduced due to the reduction in electricity usage and removal of the need for exhaust air. Lamp cost and lamp disposal cost are another major cost reduction factor. The total cost reduction was greater than 99%.

V. Conclusion

Flat panel display manufacturing continues to evolve and remain highly competitive in the demanding automobile and smartphone industries. The cost of ownership will be one of the main key factors driving the flat panel display manufacturing industry.

UV LED light source provides the means to long-term cost savings benefits, improving throughput and tool reliability without compromising tool performance, and should be the main lead technology evolution in the near future.

Acknowledgement

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