Design and Development of Ultra Violet LED Machine

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Abstract:
Photolithography techniques on a PCB are a UV exposure process that used in micro fabrication to pattern parts of a thin film of a substrate. Light is use to transfer a geometric pattern from a photo mask to a light-sensitive chemical (photoresist) on the substrate. In educational institution, most of the UV exposure process used UV Florescent lamp or Metal Halide lamps as an exposure system, both of this equipment is expensive and produce a wide UV radiation that is not suitable for the PCB which will increase the consumption of the electricity. This paper aims, to describe the development of UV exposure device using LED lighting technology with low cost, portable and suitable for education facilities. LED lighting has powerful flexible design features and can be combining in any shapes to produce a highly efficient illumination. LED lights achieve higher application efficiency because the LED is design to focus the light direct to specific location. The LEDs can frequently switched ON/OFF, bright up immediately when powered ON and has great advantages for infrastructure projects such as in exposure system. These UV LED exposures designed by using combination LED circuit with controller board to control time, relay and LCD display. The UV LED circuit use in sized 120 mm x 190 mm with 3mm LED to produce 400mm to 405 mm wavelength for UV exposure system.
Keywords: Photolithography techniques, PCB, LED technology

1.0 Introduction

Despite the fast development of the electronics industry, Light Emitting Diodes (LED) with UV-emitting are becoming increasingly popular as a light source illuminating. Like other LEDs, UV LEDs exhibit several advantages, such as lower energy consumption, longer lifetime, smaller size, and faster switching (P.Boulay, April 2018). At this time most UV LEDs emit in the longer wavelength UVA region of the UV spectrum which is less damaging. Scattering losses come from defects on the surface or within the lens component and suitable for photolithography process (Sahara, 2008). The application of UV LEDs to photolithography process of PCB production is attractive. Photolithography is a process used in fabrication to selectively remove parts of a thin film or substrate. It uses light to transfer a geometric pattern from a photo mask to a light-sensitive chemical photoresist on the substrate (Jaeger, 2002). A pattern is then aligned and projected onto the substrate using a UV light source. Photolithography and pattern transfer involve a set of process steps summarized in Figure 1.

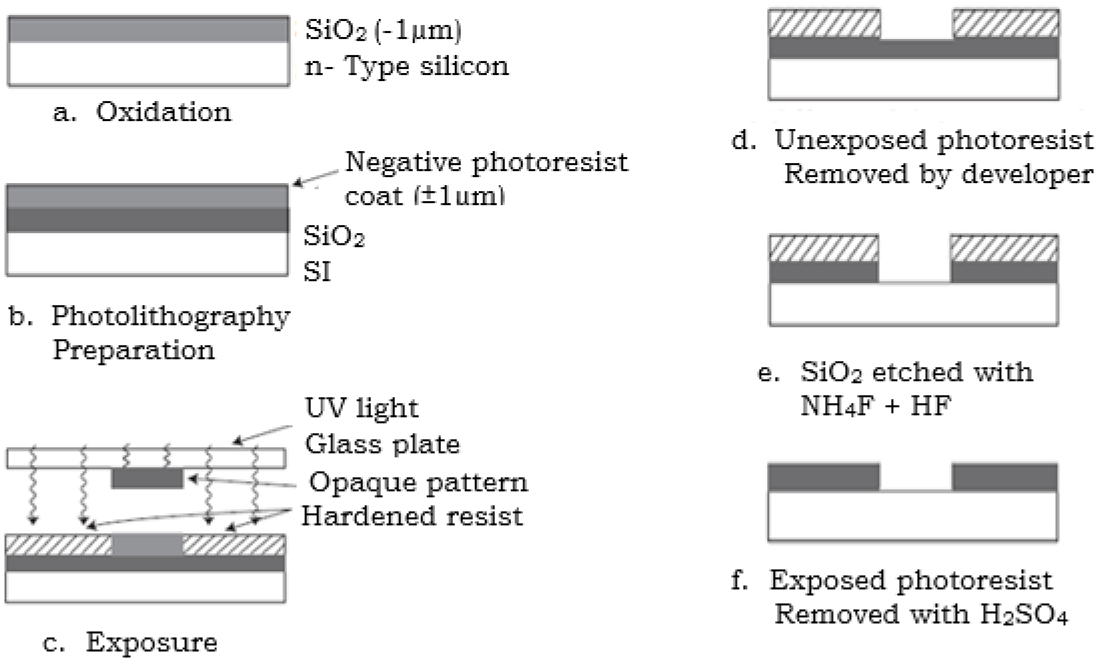


Figure 1: Basic photolithography and pattern transfer. Example uses of an oxidized silicon wafer and a negative photoresist system. Process steps include exposure, development, oxide etching, and resist stripping.

An oxidized wafer (Figure 1a) is coated with a 1 μm thick negative photoresist layer (Figure 1b). After exposure (Figure 1c), the wafer is rinsed in a developing solution or sprayed with a spray developer, which removes the unexposed areas of photoresist and leaves a pattern of bare and photoresist-coated oxide on the wafer surface (Figure 1d).The photoresist pattern is the negative image of the pattern on the photo mask. In a next step after development, the wafer is placed in a solution of HF or HF + NH_4F, meant to attack the oxide but not the photoresist or the underlying silicon (Figure1e). The photoresist protects the oxide areas it covers. Once the exposed oxide has been etched away, the remaining photoresist can be stripped off with a strong acid such as H_2SO_4 or an acid-oxidant combination such as H_2SO_4-Cr_2O_3, attacking the photoresist but not the oxide or the silicon (Figure 1f). Other liquid strippers include organic solvent strippers and alkaline strippers (with or without oxidants). The oxidized Si wafer with the etched windows in the oxide (Figure 1f) is ready now for further processing, which might entail a wet anisotropic etch of the Si in the etched windows with SiO_2 as the etch mask (Madou, 2011)

The methods commonly used to expose the photoresist are UV fluorescent lamps and metal halide lamps. This method has low efficiency due to the reflection and smoothness of low light (Syvajarvi, 2010). In addition, everything in the exposure room will be exposed to UV light. By using these two methods, it is difficult to expose simultaneously the second layer of double layer PCB. Many methods used to expose photoresist exposure and been tested including the usage of professional equipment.

There are some problems when using professional equipment such as heating time, equipment cost, sensitivity of chemical procedures and the use of printer transparency under non-vertical and non-uniform UV light illumination (Chatzakis, 179-183). For the professional purposes, efficiently and rapid production of the PCB is important to reduce the research and development time of the prototype before it is marketed.

In education institutions, such as universities, high schools and technical education centres, the objective is to produce prototypes and small serial production quickly and inexpensively. The new solution for UV exposure system is to use UV LED panels. Table 1 shows the comparison between UV LED and UV fluorescent lights that are suitable for educational facilities.

Table 1: Comparison between UV LEDs (Miroslav, 2012) and UV Fluorescent Lamp (Abd Rahman Tamuri, 2014)

	UV LEDs	**UV Florescent Lamp**
Light Emittance	Emit a narrow range of UV light wavelength but at higher concentration and energy than UV Fluorescent Lamp	Emit a slightly broader range of UV light wavelength, but at a lower concentration and energy than UV LEDs
Wavelength Characteristic	Single Peak (380nm)	Multiple peaks (254nm, 313nm, 404 nm, 437nm, and 546nm)
Power Usage	Less power than UV Fluorescent Lamp about 12VDC	Require more about 110VAC
Weight	Lighter in weight UV Fluorescent Lamp	Heavier in weight than LED UV
Life	Up to 50,000 hours (Bulbs are not replace)	About 10,000 hours of functional use (bulbs are replaced every 2 or 3 month depending on amount of use)

2.0 Problem Statement

Most exposure systems used in educational institutions are exposure systems with Fluorescent UV lamps or Metal halide lamps. Both systems are very expensive, too wide UV radiations and not suitable for the sizes of the PCB to be placed on the equipment (Miroslav, 2012). This results in a waste of electricity in the exposure system if the PCB is small in size. This UV exposure system only supports a single side PCB which has a lot of time to reveal both sides of the PCB. In addition, the timer and buzzer are not considered as a requirement of the old design of the exposure system which causes a lot of rough estimates during PCB exposure. One of the major concerns is the costing of the UV exposure system. Given the limitations of the research, this problem poses an investigation on how to build a UV exposure system at a minimal cost. Another problem is how the device can help minimize energy consumption during the PCB exposure process. Other queries related to the performance of the device include how it can support a single and double sided PCB, its ability to guarantee the best exposure time, and how devices can warn PCB fabricators when the exposure time is over.

3.0 Design and Operation Principle

Figure 3 shows the UV LED exposure device consists of housing, LED UV circuit, controller, buzzer and display unit set. Glass plates are placed in the housing on a UV LED circuit within 6 cm (where copper plate with transparent film is placed). This distance is appropriate for transparent films to be exposed to UV LED radiation generated from the UV LED circuit.

The copper plate is a printed circuit board (PCB). The transparent film has an image or a circuit design layout or a pattern. Upon the continuous exposure to the UV LED radiation for a certain time period, the circuit design layout is imprinted on the copper plate. The exposure time is displayed on the display unit. Upon completion of the exposure time, the buzzer produces sound alert.

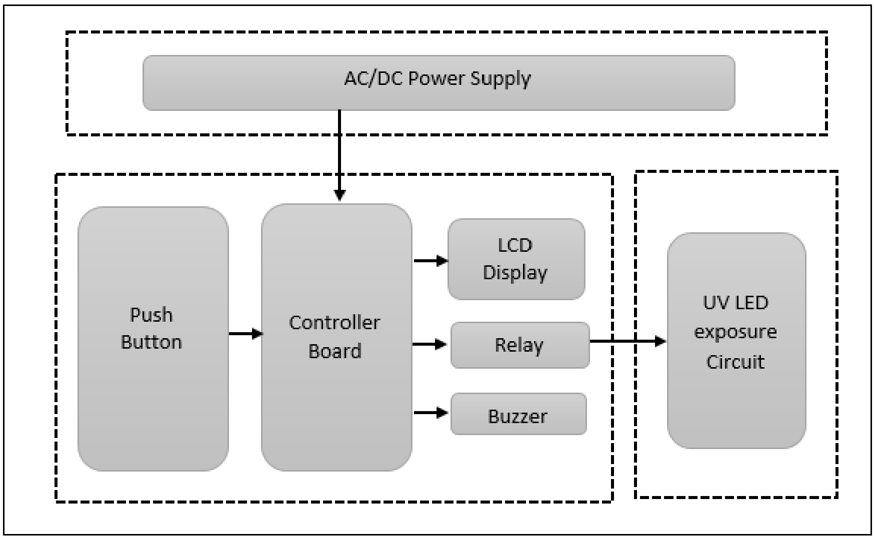


Figure 3: Block diagram of the UV LEDs exposure system

As illustrated in Figure 4, the UV LED circuit has 117 UV LEDs in 39 x 3 arrangements on a panel size of 120 mm X 190 mm. A 12V, 780mA, 9.3W switching power supply is provided to the controller and to the UV LEDs circuit. The arrangement of the UV LEDs in the LED circuit is in order of three UV LED 1, UV LED 2 and UV LED 3 in series connection with 68 ohm resistor as shown in Figure 5. The resistors limit the current passing through the three UV LEDs up to a 20mA. The distance between the LEDs is 15mm. This arrangement of the UV LEDs in the UV LED circuit enables to focus its radiation and to be directed to a specific location without the use of an external reflector, thus achieves higher application efficiency. The UV LED circuit produces 400mm to 450mm wavelength for the UV LED exposure device. The size of the UV LED circuit is 120 X 190 mm is suitable for the all standard sizes of the transparent films and PCB used, where the radiations are exposed evenly in all directions to the PCB and without any wastage of the power.

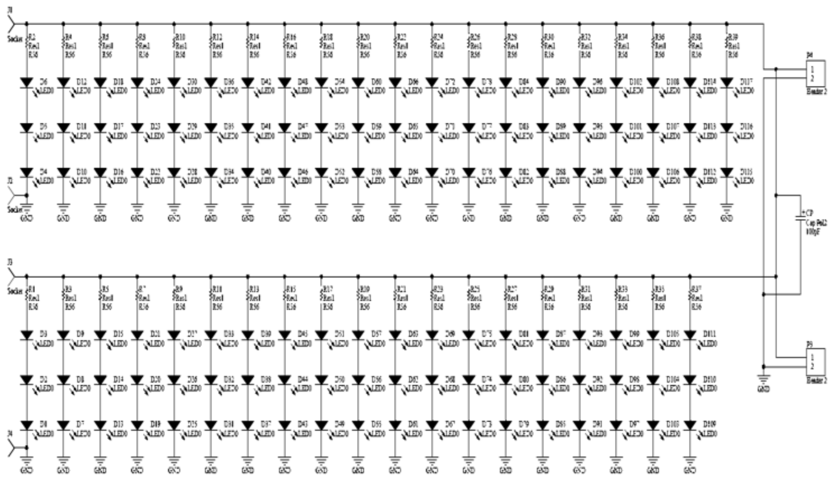


Figure 4: UV LEDs Circuit

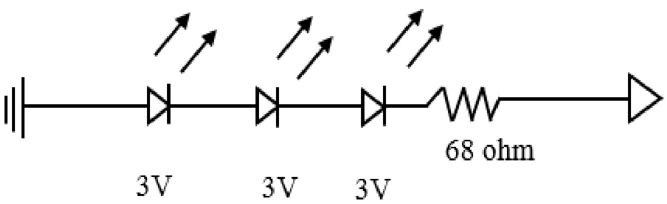


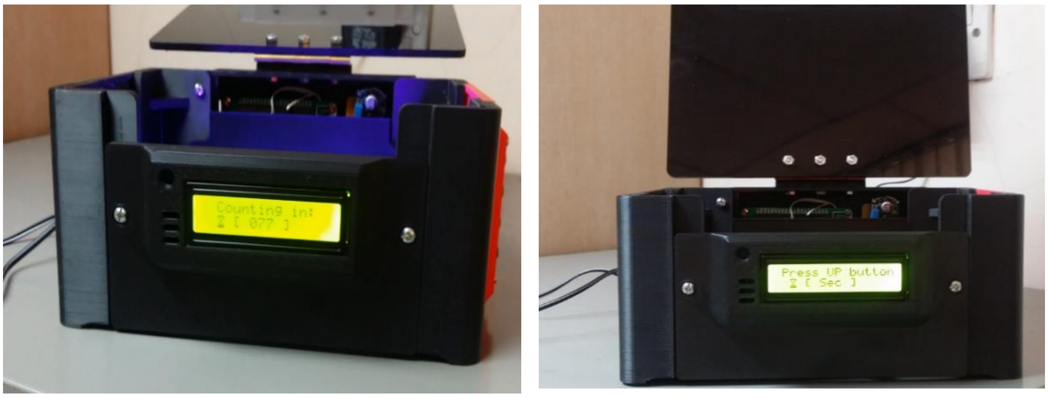
Figure 5: UV LEDs connector with resistor

In this photoresist system the controller automatically controls the exposure time depending upon the type of the transparency film used and is displayed on the display unit. Based on the exposure time, the controller controls the switching between the ON and OFF states using a relay switch arranged in the UV LED exposure device. Further, the controller is programmed to automatically control the time of the UV LEDs to direct its radiations to a specific location. The arrangement of the UV LEDs in the UV LED circuit also enables to complete this process in a lesser time between 80 seconds to 3 minutes, as it is able to deliver radiations more efficiently to the desired location depending upon the type of the transparency film used. UV LEDs can be switched on repeatedly and the LEDs bright up immediately when powered by the controller automatically. The combination of the UV LEDs circuit with the controller to control time, relay circuit, buzzer and to display data on the display unit has many advantages.

The UV LED exposure device that operated manually is provide with knobs and buttons to adjust the time. The 12V power supply is used to switch the controller and the display unit. When the button is pressed, the timer will calculate the time taken for the process and displayed on the display unit. The relay circuit triggers the UV LED circuit once the voltage reaches 12 V. The method to operate the UV LED exposure device comprises steps: switch on the power supply. Arrange the PCB board with the pattern (transparency film) in the place. Close the cover. Set timer until 75 sec. Press start button, during exposure, the timer counts down. The display unit shows counts down time until complete. When the exposure is complete the buzzer sounds three times, each time for 250 milliseconds. Once the cycle is complete, the display unit returns to the original setting.

The prototype packaged with a complete UV exposure system is shown in Figure 6. For the selected housing material Acrylonitrile Butadiene Styrene (ABS) was used by designing a housing using a 3D printer. Black coloured of ABS material is used to minimize unwanted wall reflection. Figure 6(a) shows the UV LEDs assembly and the controller circuit. Figure 6(b) shows a picture of the current operating system where UV reflection can be seen.

(a) Inside of the casing showing the UV LED assembly and controller circuit



(b) System during typical exposure

Figure 6: Photographs of the constructed UV-LED exposure system: (a) inside of the casing showing the UV LED assembly and control circuitry; (b) system during typical exposure

4.0 Testing Result

The developed prototype system has been tested to evaluate the UV LEDs capability to be exposed with different types and sizes of PCBs. Each experiment has been run a number of times for each type and size of PCBs to confirm the repeatability of the system. Furthermore, the test also determined the clarity of the images of PCBs layout and power consumption.

4.1 Different Types and Size of PCBs

The UV LED exposure device can support PCB sizes up to 125mm by 185mm PCB. The UV LEDs capability as the light source was tested by using different sizes of PCB's to be exposed. Random sizes ranging from 15mm by 15mm PCB up to 100 mm by 150mm PCB were taken for sample. The support for the single sided and double sided PCB was some of the additional features of the prototype. This test will also check the capability of the prototype in supporting double sided PCB's. Table 2 shows the result of the different sizes of PCB's exposed to UV LEDs.

Table 2: The parameters to be considered in the test (e.g. sizes of the PCB and the type of PCB) and the results of successfully exposed or not.

TYPE OF PCB	SIZE OF THE PCB	PCB was successfully exposed
Single sided	15mm x 15mm	Yes
Single sided	15mm x 20mm	Yes
Single sided	35mm x 25mm	Yes
Single sided	70mm x 30mm	Yes
Single sided	70mm x 45mm	Yes
Single sided	80mm x 25mm	Yes
Single sided	100mm x 150mm	Yes
Single sided	125mm x 185mm	Yes
Double sided	15mm x 25mm	Yes
Double sided	35mm x 40mm	Yes
Double sided	30mm x 35mm	Yes
Double sided	40mm x 40mm	Yes
Double sided	70mm x 30mm	Yes
Double sided	80mm x 50mm	Yes

During the test, the prototype was observed whether the UV LEDs can expose the optimal dimension of the PCB. Based on the data collected, the capability of the UV LED to expose the PCB worked well. Also, support for double sided PCB's worked as it should be.

4.2 Images of PCB layout size

Figure 7 shows a variety of microstructures successfully patterned on the PCB by using a UV-LED exposure system.

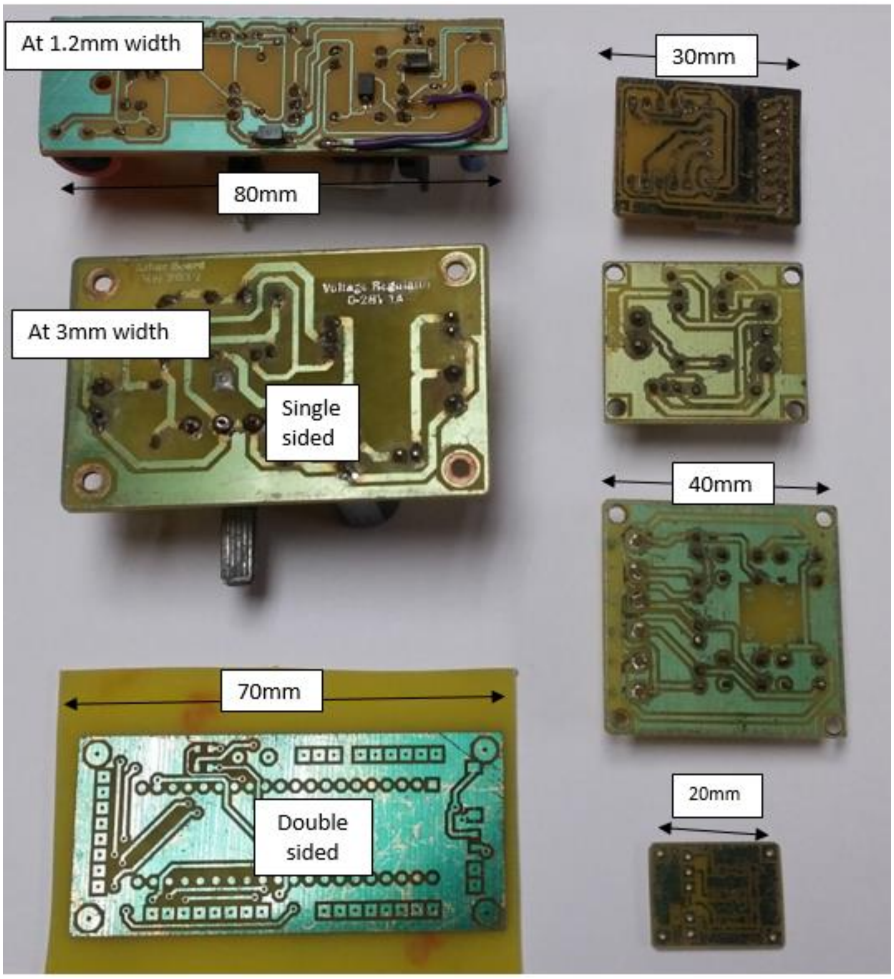
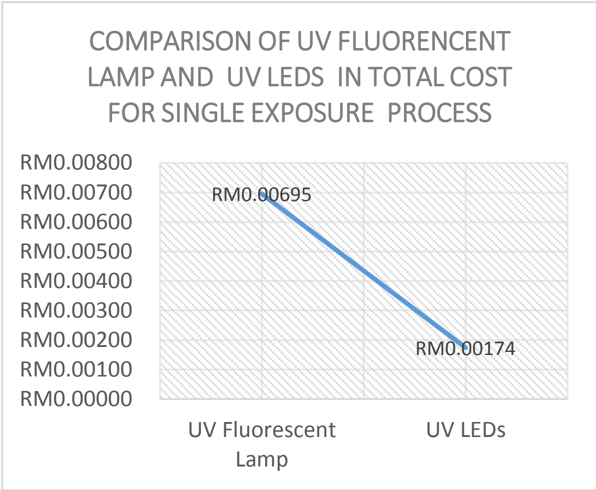


Figure 7: Images of PCB layout suitable for various applications with relatively large feature sizes.

The photo mask is separated into different parts to cover "dark areas" and "light areas" where this finding confirms the capabilities of system patterns under both types of mask designs. In dark mask areas, photoresist moulds are made for plating lines with sizes range between 1.2mm - 50mm commonly used in photo mask layout.These images are obtained from light exposure on PCB result by using the portable UV exposure machine with low cost. The result of this geometric image demonstrates that additional imaging capabilities to larger geometric patterns and can be generated using this invention machine. These samples show single and double sided from 20mm PCB size to 80mm PCB size.

4.3 Power Consumption

The result show, UV LEDs are more energy efficient than UV Florescent Lamp, economical and environment friendly. This test show the comparison of data gathered between the original UV Fluorescent Lamp exposure system and UV LEDs exposure system. The parameters to be considered in this test are the following type of PCB to be exposed, length of exposure time and cost per kilowatt hour. Figure 8 shows the performance of the commercialize UV Fluorescent Lamp and UV LEDs as alternative for exposure system.



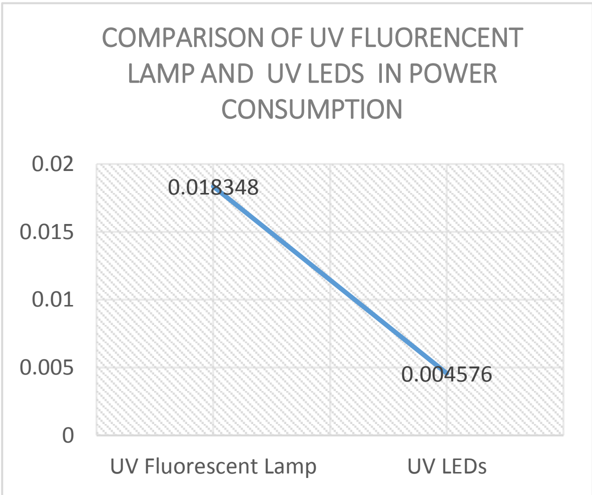


Figure 8: The comparison data of UV Fluorescent Lamp and UV LEDs as alternative for exposure system.

Based from the collected data after performing the test, it shows that using UV LEDs as the light source is far more efficient than using UV Fluorescent Lamp. LEDs were efficient in terms of cost and power consumption. In addition, the use of the UV LEDs helps the design to control the lights to be lit up to expose the optimal dimension of the PCB.

4.4 Project Return on Investment – ROI

Figure 9 shows the total price comparisons between UV Fluorescent Lamp and LED UV exposure systems. The results show UV LED exposure two times cheaper than UV Fluorescent Lamp. Apart from low cost data it also shows UV LED savings up to 67% over conventional Fluorescent UV lamps.

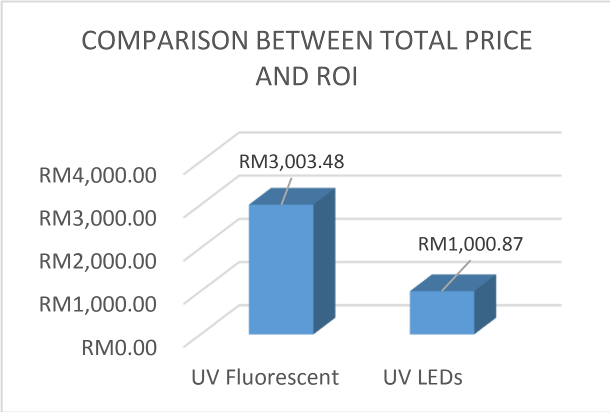
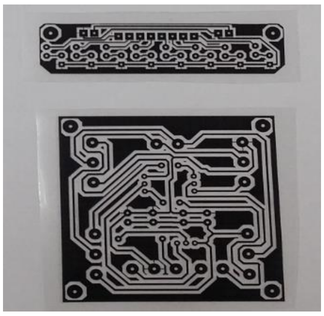


Figure 9: Total price and electricity cost for UV Fluorescent Lamp and UV LEDs

Return on Investment (ROI) = ((Project financial gain – projects cost) / projects cost)
= (2002.6075/1000.8695)
= ***2 times***

4.5. Pre-test Exposure Time

Exposure time in UV light is one of the major requirements in PCB fabrication. The test was carried out referring to the type of film and timing of exposure in order to get the best result of PCB fabrication. Two types of film are chosen for the pre-test which are transparency film and tracing paper as shown in Figure 10 (a) and (b).


a) Transparency Film

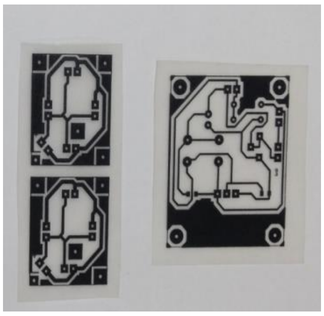

b) Tracing Paper

Figure 10: Types of film; (a) transparency; (b) tracing paper

Table 3 and Table 4 show the results obtained with the best exposure time according to the film type of transparency and tracing paper. This test aims to eliminate the rough estimation of exposure time to reduce the errors in PCB fabrication.

Table 3: Pre-test time for transparency film

Board number	Test results of the UV LEDs exposure unit	
	Exposure time	**Description**
1	50 sec	Under exposed
2	75 sec	Very good
3	100 sec	Over exposed

Table 4: Pre-test time for tracing paper

Board number	Test results of the UV LEDs exposure unit	
	Exposure time	**Description**
1	50 sec	Under exposed
2	70 sec	Very good
3	100 sec	Over exposed

Under Exposed – layout is not visible / lines are not clear; too short exposure time
Over Exposed – too long exposure time; turns the PCB to black
Very Good – layouts and lines are visible

Based on the data collected, under or over 100 seconds of exposure does not yield the best results of fabricated PCB. To obtain the best fabricated PCB, set the exposure time at 75 seconds. For tracing paper, 70 seconds is enough time to expose the PCB because the thickness of the tracing paper is less than transparency. 70 seconds of exposure will give best results in exposing PCBs to paper traces. By knowing the exact exposure time for each type of film used will facilitate PCB creators to produce the best PCB without any error during the exposure process.

5.0 Conclusion

A complete prototype using a UV LED based photolithography system has been develop and its function has been verified through a pattern of successful up to 0.1 mm upwards. This project was develop for technical education institutions improvement for the quality of education in the field of electrical and electronic engineering. Compared with other exposures system such as filament and metal, the resulting UV LEDs system exposure is much cheaper, does not require complex infrastructure to operate and offers full flexibility in exposure parameters (Farhat, February 2014). The system is portable, compact, offering low voltage DC operation and suitable in any location. It reduced the system costs and complexity making UV LED photolithography as the perfect equipment for micro fabrication applications by producing patterns in varying distances according to the thickness of the film used. Using UV LEDs will reduce double of the current cost compare to conversional equipment. This low cost UV LED exposure system has been

References

Abd Rahman Tamuri, M. A. (2014). Ultravoilet (UV) Light Spectrum of Fluorescent Lamps. The Proceedings of 8th SEATUC Symposium.

Al, A. R. (2014). Ultravoilet (UV) Light Spectrum of Fluorescent Lamps . The Proceedings of 8th SEATUC Symposium.

Chatzakis, J. (179-183). A Printed Circuit Board Exposure Device Design for Course Projects using LEDs ," Mathematical Models and Computational Methods. 2015.

Farhat, M. K. (February 2014). UV-LED exposure system for low cost photolithography. Proceedings of SPIE- the International Society for Optical Engineering.

J.K. Kim, S. P. (June 2012). UV-LED lithography for 3-D high aspect ratio microstructure patterning. " 14th Solid State Sensors, Actuators, and Microsystems Workshop, 481-484.

Jaeger, R. C. (2002). Lithography", Introduction to Microelectronic Fabrication," Upper Saddle River. United State: Prentice Hall.

Madou, M. J. (2011). Fundamentals of Microfabrication and Nanotechnology. United State: CRC Press.

Miroslav, K. A. (2012). UV Exposure Unit For PCB Prototyping,. Annals & Proceedings of DAAAM International, 693-696.

P.Boulay, P. (April 2018). Status and Trends of the UV LED Curing Industry . International Conference on UV LED technologies & applications ICULTA, 55.

Syvajarvi, M. B. (2010). Introduction:A Paradigmatic Shift? New Lighting-New LEDs Aspects on light - emitting diodes from social and material science perspectives, 9-16.