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Development of LED UV Printing Machine of Printed Circuit Board (PCB)

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Abstract

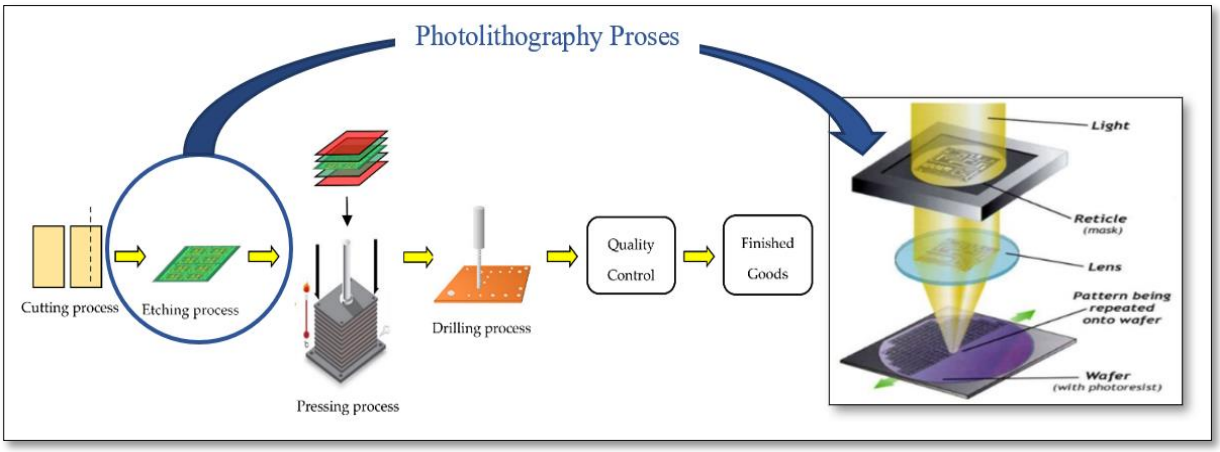
The process of photolithography is widely employed in micro manufacturing to create printed circuit boards (PCBs). To transfer a geometric design from a photo mask to a light-sensitive material (photoresist) on the substrate using light, a thin coating of the substrate must be exposed to UV light in certain areas. Typically, UV fluorescent bulbs and metal halide lamps comprise the bulk of exposure systems used in the photolithography process. Nevertheless, both technologies are very expensive and energy-intensive for educational institutions. Additionally, they are inappropriate for the sizes of PCBs that must be put on the equipment and have too broad of a UV ray. The purpose of this innovation is to use LED illumination technology to develop a low-cost, portable UV exposure system that performs well in educational settings. These UV LED exposures were constructed utilizing a combined LED circuit with a controller board to control time, relay, and LCD display. The UV LED circuit, measuring 120 mm by 190 mm and using 3 mm LEDs, produces a wavelength of 400 to 405 mm for the UV exposure system. Owing to its strong and adaptable construction, LED lighting can be incorporated into any shape to produce incredibly effective illumination. The research results indicate that because LED lights can focus light on a specific location, they have a better application efficiency. Therefore, well-designed LED illumination systems may be able to provide light to the intended place more effectively. They may also be turned on and off frequently, and they brighten instantly when powered on. The benefits of LEDs for infrastructure projects like exposure systems, which may be further enhanced for future technology have been brought to light by this research.

Keywords: UV Exposure, Photolithography Techniques, LED Technology, Printed Circuit Board

Introduction

Most of the exposure systems used in educational institutions are the exposure systems with UV tubes or exposure systems with Metal-halide lamps. Both the systems are very expensive. In addition, the UV radiations are too wide and not suitable for the sizes of the PCB placed on the equipment. This results in wastage of the electrical energy used by the exposure system. The UV Exposure systems that are currently available in the market are very heavy, bulky and requires large space to accommodate it. Therefore, there is a need for a portable exposure device which overcome the above problems.

Even with the electronics industry's rapid growth, UV-emitting Light Emitting Diodes (LEDs) are becoming more and more common as illumination sources. Like other LEDs, UV LEDs have several benefits, including faster switching, smaller size, longer lifespan, and lower energy use. Furthermore, the feasibility of utilizing UV LEDs as a light source in the exposure system has been demonstrated. On the other hand, an array of UV LEDs may readily emit almost parallel light beams without the need for a lens, unlike point light sources that require one to produce parallel light beams. It is appealing to use UV LEDs in the photolithography step of PCB manufacturing. A fabrication technique called photolithography is used to remove specific portions of a thin film or substrate.



Source: https://loharanuradha80.medium.com/lithography-methods-in-fabrication
Figure 1: Basic photolithography and pattern transfer Printed Circuit Board (PCB)

Commonly, metal halide lamps and UV fluorescent lamps are employed to expose the photoresist. The low light's smoothness and reflection make this procedure inefficient. All items within the exposure room will also be subjected to UV light. It is challenging to expose the second layer of a double-layered PCB simultaneously utilizing these two techniques. A variety of exposure techniques, including the use of specialized equipment, have been tested for photoresist exposure. Using specialized equipment, it is essential to make PCBs fast and effectively to reduce the amount of time needed for research and development of the final product that will be put on the market. The main requirement in educational institutions like colleges, high schools, and technical education centres is the speedy and low-cost production of prototypes and small batches. UV LED panels are the modern option for UV exposure systems.

Literature Review

Nassajfar et al (2021) stated Printed Circuit Boards (PCBs) are a fundamental component in almost all electronic products, and circuits, devices and chips. Printed Circuit Board (PCB) fabrication is a crucial aspect of electronic manufacturing, and the efficiency of the photolithography procedures plays a pivotal role in achieving precise and reliable PCBs. Research by Shamkhalichenar et al (2020) show the diminishing manufacturing price of PCBs due to the rapid growth of the electronic industry provides opportunities to adopt this technology for the fabrication of affordable disposable electrochemical applications. Traditionally, exposure systems utilizing metal halide or UV fluorescent bulbs have been prevalent in educational establishments. However, these systems are often plagued by high

costs, broad UV radiation, and limitations in accommodating varying PCB sizes. The wastage of electrical energy further diminishes the sustainability of these exposure systems. There are various techniques developed by researchers in the technique of producing PCB as studied by (Nevliudov et al., 2022; Sudheshwar et al., 2023).

Existing Challenges

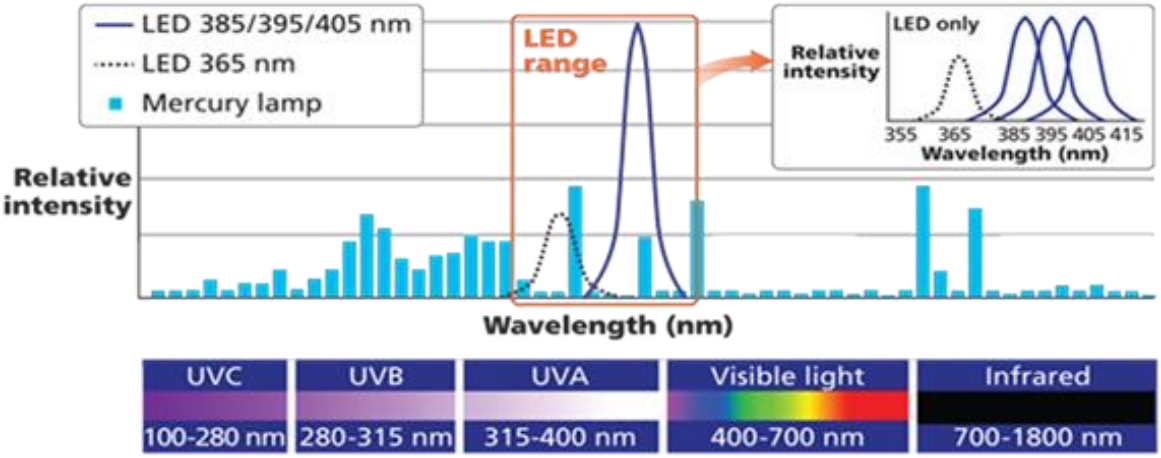
The challenges associated with conventional exposure systems have fuelled a quest for alternative technologies that can address the limitations and inefficiencies prevalent in educational settings. According Castano (2022) the need for a cost-effective, portable solution with the ability to handle different PCB sizes has driven the exploration of advanced illumination technologies. Nevliudov et al (2022) stated the PCB production cost consists of many factors: the use and depreciation of machines and installations, the required amount of consumables and resources, the accuracy class of the printed circuit board, the production complexity and much more.

LED Illumination Technology

One emerging solution lies in the utilization of Light Emitting Diode (LED) illumination technology. LED lighting, known for its versatility and efficiency, has become a promising candidate for addressing the shortcomings of traditional exposure systems. LEDs can be integrated into various shapes, allowing for highly efficient illumination. Their ability to concentrate light in specific areas enhances application efficiency, making them particularly suitable for precision tasks like PCB fabrication. Based on resea

Advantages of LED Technology in UV Exposure Systems

The advantages of LED technology in UV exposure systems are manifold. The LEDs' energy efficiency and the capability to be turned on and off repeatedly align with the demands of educational settings where the equipment may be used intermittently. The instant brightening upon power-up and the ability to generate a specific wavelength in the UV spectrum (400 to 405 nm, in this case) contribute to the precision required in photolithography procedures. Based on research Chen C.-F. et al. (2022) stated the UV-LED exposure machine is expected to gradually replace traditional exposure equipment and become the mainstream machine used in educational institution.



Source: https://rimotec.nl/uv-led/

Figure 2: Wavelength Characteristic Between LED and Mercury Lamp

Integration of LED Circuit with Controller Board

To harness the full potential of LED illumination technology, UV LED exposure systems have been developed with a combined LED circuit and a controller board. This integration facilitates effective management of time, relay functions, and includes an LCD display for user-friendly operation. The compact dimensions of the UV LED circuit (120 mm by 190 mm) with 3 mm LEDs make the system portable while ensuring a reliable and consistent UV exposure process for PCB fabrication.

Methodology

There are many studies done on teaching aids developed through innovation in technical education institutes. This statement is supported by Evangelista (2022); Maheswaran & Langenbach (2022); Nahrowi & Hariyanto (2022) stating that to reform engineering education by moving away from the boundaries of traditional classroom-based approaches to project-based approaches using real world situations. This new teaching approach can improve the effectiveness of engineering education can provide a more significant learning experience and improve students' understanding especially in electrical field.

According to Selasih et al (2017) the instructional design process involves five steps: analysis, development, design, implementation, and evaluation (ADDIE). The concept of instructional development design is the process of designing learning through instruction where the focus is on learning and not on teaching. The concept has been around since the early 1950s, the ADDIE model first appeared in 1975. It was created by the Educational Technology Center at Florida State University for the United States Army and then quickly adapted by all the U.S. Armed Forces.

Research and Development (R&D) methods are research that systematically aims to find discoveries, formulas, refine, develop, produce, test the effectiveness of products, models, methods / strategies, services, procedures that are specific, effective, new, efficient, productive, and meaningful. This research uses the ADDIE model. This model is adapted for the following reasons:

i. easier than other models.
ii. easy to learn.
iii. The structure is systematic; step one to step five.
iv. the procedure cannot be done randomly.

Analysis Phase

This phase shall be gather information regarding the existing UV Exposure machine in the market or other education institution.

Table 2
Comparison of Exposure Machine Used in Educational Institute

	LED LAMP	METAL HALIDE LAMPS	LED SCREEN EXPOSURE	UV FLUORESCENT
LIGHT SOURCE OF EXPOSURE MACHINE				
ESTIMATED COST	~ RM200	~ RM 4500	~ RM20,000	~ RM3775
MACHINE SIZE	100cm x 50cm x 1m	1m x 50cm x 1m	1 m x 50cm x 1m	20cm x10 cm x 10cm
POWER CONSUMPTION	1 Amp	20 Amp	6 Amp	3 Amp

Design Phase

This LED UV machine will design with commercialize aspect, portable and lower cost suitable for educational purposes. The system consists of housing, UV LED circuit, controller, buzzer, and display unit set. The benchmarking of existing machine is considering use UV florescent or Metal Halide lamps with high cost, high power consumption and produce a wide UV radiation that is not suitable for the PCB prototyping size.

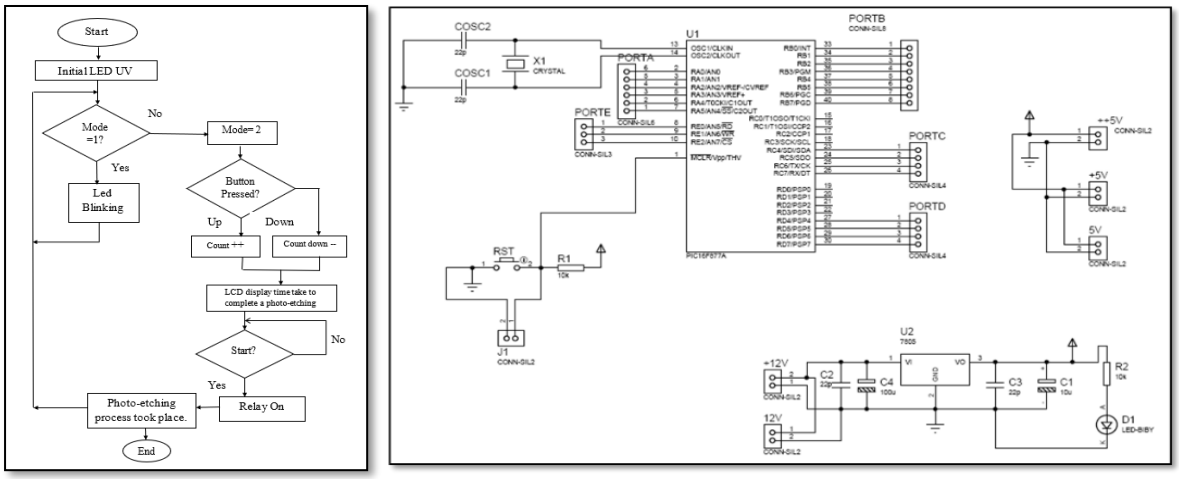


Figure 3: Flowchart and Controller Board Circuit Design

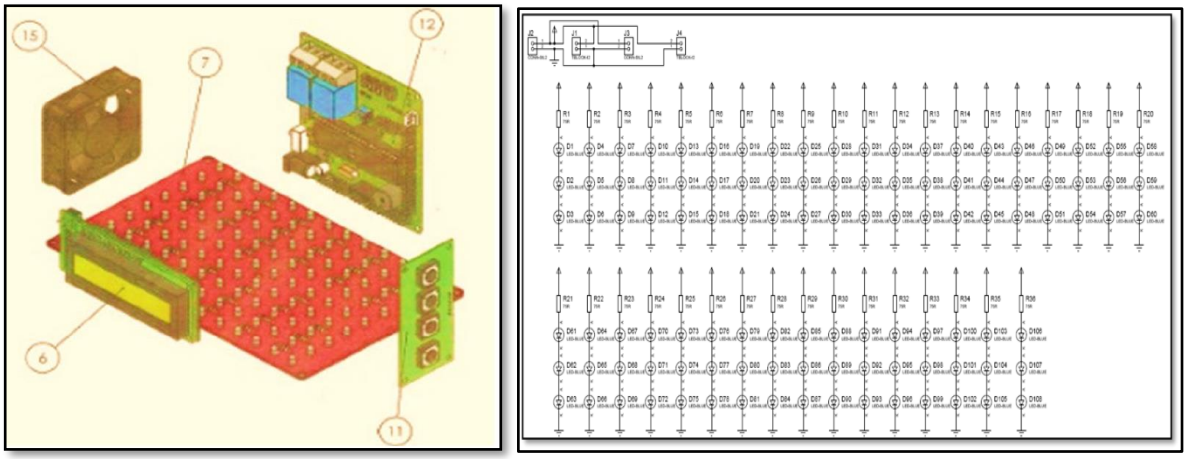


Figure 4: Casing and LED UV Panel Design

Development Phase

Based on Phase Analysis and Design and Development, the LED UV Printing Machine have been developed

i. LED UV Printing Machine comprises of a housing with a door in which a LED UV circuit, a controller, a buzzer, and a display unit are arranged. A glass plate is arranged inside the housing above the LED UV Panel circuit with an estimated gap, on which a copper plate with a transparent 5 film is placed, in such a way that the transparent film is exposed to the LED UV radiations 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 period, the circuit design layout is imprinted on the copper plate. The exposure time is displayed on the 10-display unit. Upon completion of the exposure time, the buzzer produces sound alert. The housing is made of an ABS material and by using 3D printer. The material of the housing is not limited to the ABS material as shown in Figure 5.

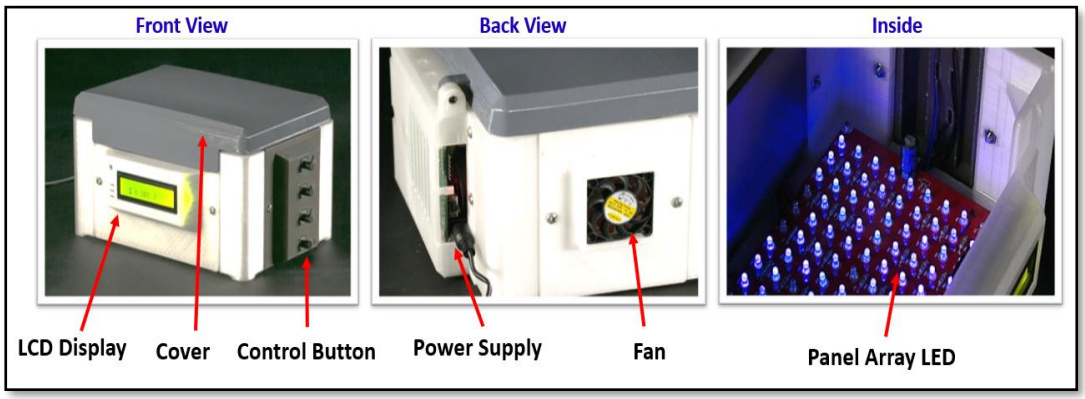


Figure 5: Front, Back and Inside View of LED UV Printing Machine

Implementation and Evaluation Phase

The implementation phase is the fourth phase and is very important to determine whether the development objectives are achieved. The last phase in the ADDIE model is the evaluation

phase which involves the evaluation process from users as a formative evaluation during the design process and after the development process has been completed.

PCB Transparent Paper PCB and Transparent Paper

Figure 5: Steps to set up PCB and Transparent Paper on Glass

The manual to operate the LED UV Printing Machine has been fully prepared with safety guideline measures as shown in Figure 6.

Figure 6: LED UV Printing Machine Manual and Safety Guideline for Users

Data Analysis and Findings

Evaluation is a phase to find out the effectiveness of the LED UV Printing Machine that has been developed. This evaluation has been excuted through a questionnaire adapted from the Post-Study System Ability Questionnaire (PSSUQ). Descriptive statistical methods are used to analyze and evaluate the functionality and effectiveness of use by looking at the mean score value. This questionnaire was given to UV LED UV Printing Machine who are teachers and final year students at Slim River Vocational College, Perak that have used this machine. Overall data shows that students are satisfied with this UV printing machine with a mean score above 3.34 (Pallant, 2007). The highest score mean 4.59 of the findings the item in section C learning ability that shown the users can choose a single-layer mode or two-layer mode for printing PCB board according to the desired time option

Table 2

Student Evaluation of Effectiveness Using UV LED Printing Machine

ITEM NO	ITEM	SCORE MEAN	STD DEV σ
SECTION A: MACHINE DESIGN			
1	The design of this machine is very attractive, lightweight and portable to carry everywhere.	4.50	0.786
2	The machine is very user-friendly.	4.33	0.594
3	The method of using this machine is very simple and convenient.	4.44	0.784
SECTION B: THE FUNTIONALITY			
4	Digital timer display makes it easy for users to choose the time mode it takes to print	4.50	0.514
5	Users can choose a single-layer mode or two-layer mode for printing PCB board according to the desired time option.	4.56	0.618
6	Users can easily and quickly do the printing process anywhere as this machine only requires a 12V, 9.3W power connection.	4.50	0.616
SECTION C: EASY TO BE USED			
7	The work instructions for using this machine are very concise and do not require a lengthy description.	4.11	1.023
8	This machine does not require a complicated work instruction manual.	4.39	0.502
9	Anyone can use this machine for any production of PCB circuits in developing any electronic application.	4.44	0.502
10	Each printing process takes no more than 2 minutes to produce the perfect print on the PCB board.	4.47	0.514
SECTION D: LEARNING ABILITY			
11	This machine is able to encourage students to produce circuit designs or electronic projects more creatively, innovatively and effectively.	4.44	0.511
12	This machine can be used in all institutions of higher learning that offer technical engineering involving the production of final student projects.	4.59	0.507
13	This machine is very helpful in facilitating the teaching and learning process especially in the field of producing circuit design and electronic projects.	4.53	0.514
SECTION E: THE SATISFACTION			
14	This machine helps to make the learning process more interesting.	4.50	0.514
15	This machine has interesting features and designs.	4.39	0.608

16	This machine helps personally to those who like to be creative in use to produce electronic product		
SECTION F: THE RESULT OF USE			
17	The machine is very convenient and practical to use.	4.39	0.60
18	The machine must be present in all technical learning institutions that offer programmes or courses in related fields.	4.56	0.511
19	This machine is suitable for use at the level of technical education institutions.	4.50	0.514
20	This machine use can be extended to other levels such as primary and secondary schools	4.50	0.514

Source: This questionnaire is adapted from the Post Study System Capability Questionnaire (PSSUQ)

Discussion and Conclusion

The LED UV Printing Machine generate significant cost, energy, and space savings compared to other technologies. Finding by Pode (2020) state the LED UV technology has many advantages over other light sources like long operational life (about 100,000 hours), low power consumption, much better energy efficiency and much more eco-friendly because the LED lights are free of toxic chemical. The study by Bermundo (2022), Suryanto A. and Istiqomah (2022); Sukardjo et al (2022) stated the developed trainer is an effective instructional device to enhance students' knowledge and skills. The LED lighting has powerful flexible design features and is combined in any shape to produce highly efficient illumination. The study successfully addressed the limitations associated with conventional methods, such as high costs, broad UV radiation, and challenges in accommodating diverse PCB sizes. The following points provide a comprehensive discussion of the findings:

i. **Efficiency and Versatility of LED Technology**
   The comparison between LED UV Printing Machine and UV fluorescent lamps highlighted the superior characteristics of UV LEDs, including narrow UV light wavelength emission, lower power usage, lighter weight, and an extended lifespan. These factors contribute to the efficiency and cost-effectiveness of the UV LED exposure system.
ii. **Advantages in Educational Settings:**
   The specific requirements of educational institutions, including colleges, high schools, and technical education centres, were considered in the design of the LED UV Printing Machine. The ability to produce prototypes and small batches rapidly and at a low cost aligns with the educational objectives of facilitating practical learning experiences.
iii. **Integration of LED Circuit and Controller Board:**
   The integration of a combined LED circuit with a controller board was identified as a crucial element in managing time, relay functions, and providing a user-friendly interface through an LCD display. This integration enhances the overall usability and efficiency of the UV LED exposure device.
iv. **Successful Exposure Across Different PCB Sizes:**
   The results of the test confirmed the successful exposure of PCBs across various sizes, validating the UV LED's capacity to deliver precise and reliable patterns. The system's

ability to accommodate different PCB dimensions is a crucial aspect for its practical utility.

Acknowledgement

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