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UV LED Printing Device for PCB Fabrication

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Abstract: Photolithography is commonly used to fabricate printed circuit boards (PCBs) in micromanufacturing. It involves UV exposure to pattern portions of a thin film of a substrate before a geometric design is transferred from a photo mask to a light-sensitive substance (photoresist) on the substrate using light. Conventionally, metal halide lamps and UV fluorescent bulbs make up most of the exposure systems during photolithography. However, both systems are highly costly in educational establishments and consume high electrical energy. Moreover, they also have too broad UV radiation and are not appropriate for the sizes of PCBs that need to be mounted on the apparatus. Hence, this innovation aims to create a low-cost, portable UV exposure system that works well in educational settings by utilizing LED illumination technology. In order to manage time, relay, and LCD, these UV LED exposures were built using a combined LED circuit with a controller board. With a dimension of 120 mm by 190 mm and 3 mm LEDs, the UV LED circuit generates a wavelength of 400 to 405 mm for the UV exposure system. Due to its powerful and flexible design capabilities, LED lighting may be integrated in any shape to create highly efficient illumination. The testing result shows that LED lights have higher application efficiency due to its ability to concentrate light in one area. Therefore, well-designed LED illumination systems may deliver light to the intended spot more effectively. They also brighten up instantly when powered on and can be turned on and off repeatedly. This research has highlighted the advantages of LEDs for infrastructure projects, such as exposure systems, which could be further developed for future technology.

Keywords: UV exposure; Photolithography techniques; LED technology; PCB; Education

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1. Introduction

LED lights are becoming the primary source of energy-efficient lighting (Pode, 2020). Even with the electronics industry's rapid growth, UV-emitting light-emitting diodes (LEDs) are becoming increasingly common as illumination sources. Similar to 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 needing a lens, unlike point light sources that require one to produce parallel light beams. Therefore, using UV LEDs in the photolithography step of printed circuit board (PCB) manufacturing is appealing.

Photolithography is the process used to fabricate semiconductor devices (Inelmatic, n.d.). Metal halide lamps and UV fluorescent lamps are commonly employed to expose the photoresist. However, the low light's smoothness and reflection make this procedure inefficient. Moreover, all items within the exposure room will also be subjected to UV light. In addition, it is challenging to expose the second layer of a double-layered PCB simultaneously utilizing these two techniques. Hence, various exposure techniques, including specialized equipment, have been tested for photoresist exposure.

In professional equipment employment, a few issues to consider in PCB fabrication, especially in photolithography, heating times, equipment expenses, chemical procedure sensitivity, and printer transparency in non-vertical and non-uniform UV light illumination. However, educational institutions like colleges, high schools, and technical education centres prioritize prototypes, which are speedy and low-cost production of prototypes and small batches. Therefore, using specialized equipment to make PCBs fast and effective is essential. Therefore, this paper aims to highlight the UV LED panels, which are the modern option for UV exposure systems and can reduce the time needed to research and develop the final product that will be put on the market.

2. Literature Review

PCB design and fabrication are critical processes in producing electronic devices (Hillman Curtis, 2022). The efficiency of the photolithography procedures plays a pivotal role in achieving precise and reliable PCBs. 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, knowing that cost is critical for developing reliable and viable devices (Castaño, 2022). The wastage of electrical energy further diminishes the sustainability of these exposure systems. The comparison of UV LED and UV fluorescent lights that are appropriate for use in educational buildings is presented in Table 1.

Table 1. Comparison between UV LEDs and UV Fluorescent Lamp (Nails, n.d.)

	UV LEDs	**UV Fluorescent 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

	UV LEDs	**UV Fluorescent Lamp**
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 replaced)	About 10,000 hours of functional use (bulbs are replaced every 2 or 3 months depending on amount of use)

2.1 Existing Challenge

The challenges associated with conventional exposure systems have fuelled a quest for alternative technologies to address the limitations and inefficiencies in educational settings. The need for a cost-effective, portable solution that can handle different PCB sizes has driven the exploration of advanced illumination technologies.

2.2 LED Illumination Technology

LEDs are highly efficient and consume less energy compared to traditional light sources. (Wan, n.d.) It has been developed commercially for about 25 years and is already employed in various lighting products. (Pode, 2020) One emerging solution is using Light 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 suitable for precision tasks like PCB fabrication.

2.3 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.

2.4 Integration of LED Circuit with Controller Board

UV LED exposure systems have been developed with a combined LED circuit and a controller board to harness the full potential of LED illumination technology. This integration facilitates the effective management of time relay functions and includes an LCD 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.

3. Objectives

1. Assess the limitations of traditional UV exposure systems: Examine the drawbacks associated with conventional metal halide or UV fluorescent bulb exposure systems in educational settings, highlighting issues such as high costs, broad UV radiation, and limitations in accommodating diverse PCB sizes.
2. Evaluate the viability of LED illumination technology: Investigate the advantages of LED illumination technology, emphasizing its cost-effectiveness, flexibility in design and energy efficiency,
3. Analyse the integration of LED circuit and controller board: Examine the technical aspects of integrating a combined LED circuit with a controller board, focusing on its role in managing time, relay functions, and providing a user-friendly interface through an LCD.

4. Methodology

A UV LED exposure circuit, controller, buzzer, and display unit are arranged in a housing with a door, as depicted in Figure 1, to form a UV LED exposure device. A copper plate with a transparent film is mounted atop a glass plate positioned inside the housing above the UV LED circuit with an expected spacing, exposing the transparent film to the UV LED radiations from the UV LED circuit. A printed circuit board is the copper plate (PCB). The translucent film features a pattern, an image, or a circuit design layout. After being continuously exposed to UV LED radiation for a predetermined amount of time, the circuit design layout is imprinted on the PCB.

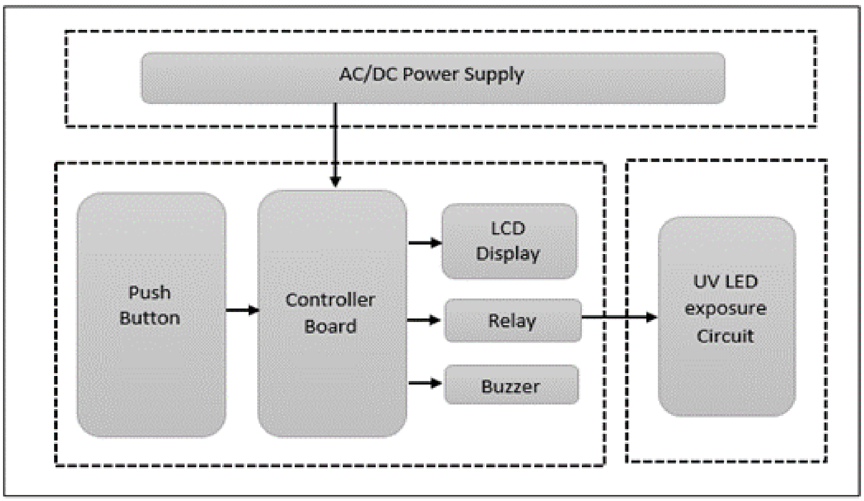

Figure 1. Block diagram of the UV LED exposure system

5. Results

The UV LED exposure device prototype was designed to support single- and double-sided PCBs up to 125 mm by 185 mm. In the prototype testing process, PCBs of various sizes were used to test the UV LEDs' performance as a light source. Table 2 shows the result for samples of single-sided PCBs exposed to UV LEDs in random sizes ranging from 15 mm x 15 mm to 125 mm by 185 mm. This test also determined whether the prototype could accommodate PCBs with two sides.

Table 2. The UV LED Exposure Test Result

Type of PCB	Size of the PCB	PCB was successfully exposed
Single sided	15mm x 15mm	Yes
Single sided	35mm x 25mm	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

From this table, the data gathered indicates that the UV LED's capacity to expose the PCB was successful. This test result shows the prototype's ability to reveal the PCB's ideal dimension via UV LEDs. Additionally, a double-sided PCB support function was discovered as intended.

A range of microstructures that were effectively patterned on the PCB with a UV-LED exposure system are depicted in Figure 2. To cover "dark areas" and "light areas," the photomask is divided into separate sections. This finding validates the system patterns' capabilities under both mask designs. Photoresist moulds are utilized in dark mask sections to plate lines with diameters ranging from 1.2 mm to 50 mm, frequently employed in photomask layout.

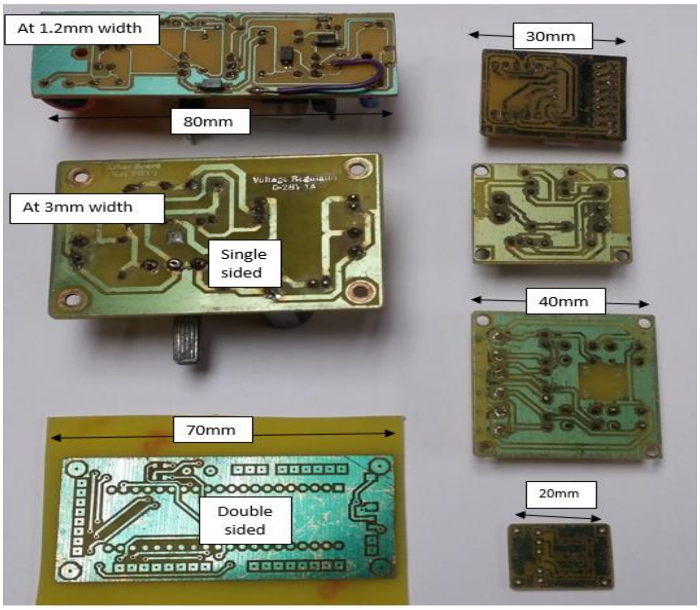

Figure 2. Images of PCB layout suitable for various applications with relatively large feature sizes.

6. Discussion

The UV LED exposure system developed for PCB fabrication significantly advances over traditional exposure systems utilizing metal halide or UV fluorescent bulbs. The study successfully addressed the limitations of 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:

6.1 Efficiency and Versatility of LED Technology

The comparison between UV LEDs 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.

6.2 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 UV LED exposure system. The ability to produce prototypes and small batches rapidly and at a low cost aligns with the educational objectives of facilitating practical learning experiences.

6.3 Integration of LED Circuit and Controller Board

Integrating 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. This integration enhances the overall usability and efficiency of the UV LED exposure device.

6.4 Successful Exposure Across Different PCB Sizes

The test results 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 crucial for its practical utility.

6.5 Microstructure Patterning

The images of PCB layouts displayed in Figure 2 showcase the effective patterning of microstructures using the UV-LED exposure system. The system's capability to cover both "dark areas" and "light areas" with separate sections of the photomask demonstrates its flexibility and suitability for diverse applications.

7. Recommendations

7.1 Further Testing and Optimization

Conduct further testing under different environmental conditions and with a broader range of PCB designs to assess the system's robustness. Continuous optimization of the UV LED exposure device may enhance performance and reliability.

7.2 Integration with Educational Curricula

Collaborate with educational institutions to integrate the UV LED exposure system into relevant curricula. This can promote hands-on learning experiences for students in electronics and manufacturing programs, fostering practical skills development.

7.3 User Training and Documentation

Develop comprehensive user manuals and training materials to facilitate the effective use of the UV LED exposure device in educational settings. Clear instructions and guidelines will contribute to the system's successful adoption and operation.

7.4 Cost Analysis and Affordability

Conduct a detailed cost analysis to quantify the economic benefits of adopting the UV LED exposure system compared to traditional methods. Highlight UV LEDs' cost savings, energy efficiency, and long lifespan to emphasize the system's affordability over time.

7.5 Market Accessibility

Explore avenues for making the UV LED exposure system commercially available to a broader audience. Consider partnerships with industry stakeholders, distributors, or educational suppliers to increase accessibility and promote widespread adoption.

8. Conclusion

In conclusion, developing a low-cost, portable UV LED exposure system for PCB fabrication demonstrates significant potential for transforming educational and manufacturing practices. By addressing the limitations of traditional exposure systems, this innovation opens up new possibilities for efficient, cost-effective, and precise PCB production in educational settings and beyond.

Author Contribution:

Wan Azizah Wan Mahmud: Conceptualized and designed the study, led the development of the UV LED printing device, and guided the research methodology. She was responsible for project supervision, data analysis, and the initial drafting of the manuscript.

Siti Norazma Muhamood: Conducted the literature review, assessed traditional versus LED-based exposure technologies, and analyzed the efficacy of LED technology for PCB photolithography. She contributed to data collection, experimental setup, and manuscript revisions.

Nor Farahwahida Mohd Noor: Focused on the technical integration of the LED circuit and controller board, ensuring proper function of relay systems and the LCD interface. She participated in device testing, data validation, and assisted with the final manuscript editing.

All authors contributed to the data interpretation, manuscript refinement, and approved the final version for publication.

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Conflict of Interest: The authors declare no conflict of interest related to this study.

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