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Modern Smart Street Light Monitoring Systems

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Abstract: This study highlights the importance of Modern Street light control systems over traditional ones, with LED lamps emerging as the most suitable choice due to their advantagessuch as reduced heat production, lower electricity consumption, and extended lifespan. The main goal is to enhance system efficiency by minimizing unnecessary electricity loss during daylight and when lighting is not required. Automating street lights using LDR and PIR sensorsin conjunction with Arduino Uno offers a cost-effective and secure solution, eliminating the drawbacks of manual switching and simplifying cost reduction and maintenance. Additionally,applying a ZnO coating to the street light casings provides effective protection against dust andmoisture, resulting in efficient lighting. The process involves sol-gel deposition of ZnO nanoparticles on silica glass substrates, followed by pre-annealing and repeated dip coating. Annealing at temperatures between 450°C and 600°C further improves the results. The uniformand defect-free coatings are confirmed by SEM images, while transmission spectra reveal over80% penetration of visible light (400 nm to 900 nm). Lower precursor concentrations lead to better penetration of light below 300 nm wavelength.
Index Terms: Arduino, Super hydrophobicity, Energy Saving

I. INTRODUCTION

One of the major components of a city's infrastructure, street lighting also contributes significantly to our traffic and pedestrian safety. At night or in low-light conditions, street lightsare utilised to illuminate the surroundings. It provides a clear view of the road and seamlesslyencourages traffic[1-2]. Still adapting the conventional street lighting system even in today's modern day world has numerous problems, including sodium vapour lamps, an unstable supply of energy, and a high labour requirement, all of which gradually drive up maintenance costs toa significant level and make it difficult to identify and fix errors [3]. The wire system, which consistently stops the ongoing services in a typical system, is the main culprit. The services are suspended because of inclement weather or other wire-related technical issues[4-5]. Currently, the street lighting system is manually operated, necessitating the deployment of officials to inspect the state and damage to any lights that cannot be detected automatically. These issues lead to extremely high maintenance costs[6-7].

Automation systems are preferred over manual mode because it reduces the use of energy to save energy. IoT-based technology will provide higher levels of services in the futureyears, effectively altering how individuals go about their daily lives[8-10]. Among the many categories where IoT is well established are improvements in medicine, energy, gene therapies,agriculture, smart cities, and smart homes.

Regarding the street lighting, it has continued to advance more important requirements. Basically, a standard road light cannot maintain the power as a result[11-12]. When the lights are on, they will always remain on unless someone does something to turn them off. So that there is more use of both financial consumption and assistance. It could be necessary to constantly monitor the board[13-16].

The IoT based centralized system used for street light monitoring is known as the street light control system. Based on PIR and LDR state, lights are automatically switched between ON and OFF[17-18].Since LED has many benefits, including high efficiency, long life, high reliability, and low power consumption, it has been the best potential light source for the next-generation lighting.Status information is stored in the PIC controller and also monitored over all status in the control base station via Zigbee communication channel[19-22].


Figure 1 – Prototype of automatic street lighting system[23]

On the other hand, silica glass used in streetlight applications can encounter significantchallenges related to the accumulation of dust and water[24-26]. Dust particles settling on thesurface of the glass over time can have a detrimental effect on its optical transparency, reducinglight transmission and overall brightness. Water accumulation poses another challenge for silica glass in streetlights [27-28]. Moisture can lead to water staining and fogging, affecting the optical clarity of the glass. Regular cleaning and maintenance protocols should be implemented to remove water stains and prevent fogging. In order to overcome these demerits,it's always better to create superhydrophobic surfaces on silica glass which is used for streetlight applications [29-31]. The sol-gel method is a versatile and precise technique for preparing superhydrophobic coatings with numerous advantages. It offers excellent control over the coating properties, allowing for customization based on specific requirements. The method provides strong adhesion between the coating and the substrate, ensuring long-term durability and stability of the superhydrophobic surface [32-35]. Furthermore, sol-gel coatingscan maintain the transparency of the underlying material, making them suitable for applicationswhere optical clarity is crucial, such as silica glass [36-37].

ZnO (zinc oxide) is crucial for superhydrophobic coatings due to its ability to create rough surface structures, exhibit inherent hydrophobicity, enable self-cleaning properties, and provide durability and stability. It can be applied to various substrates and offers flexibility in the coating process[38-39].

Analyzing auto-intensity control of LED street lights based on LDR and PIR motion sensors and the implementation of ZnO coating on the street light covering for super- hydrophobicity is the primary goal of this study. Aluminum and its alloys have been extensively preferred for many applications because of their excellent mechanical properties hence pole can be made by aluminum alloys [83-86].

They are the first choice of researchers and engineers because of their low density, good heat and electric conductivity, resistance to corrosion and high endurance[84-85].

Aluminium metal matrix composites play a very significant role in the modern world because of their versatile properties such as high strength to weight ratio, ductility, high recycle potential, corrosion resistance,[92-93] electrical and thermal conductivity along with that aluminium alloys have slighter tensile strength and wear property[89-90]

II. SELECTION OF LAMP

The first step in having an energy-efficient lighting system is choosing the proper bulb.Furthermore, given that glare and discomfort for pedestrians can result in fatal accidents in cities. Currently, High Pressure Sodium (HPS) or Metal Halide (MH) bulbs are still the most common street light bulbs used in most cities. Since they use a lot of energy, these bulbs are regarded as inefficient. Additionally, they require periodic extensive maintenance and have a shorter lifespan than Light Emitting Diodes (LEDs), which raises the cost. For instance, an HPS lamp can last between 12,000 and 24,000 hours, has a lumen output of 45–160 per watt, and needs up to 15 minutes to ignite [40-43]. Additionally, it uses up to 400W of power, contains mercury and lead, and has a low Colour Rendering Index (CRI) for yellow light [44].

LED lamps, in contrast to conventional bulbs, have the following qualities:

1) Offer longer lifespans between 50,000 and 100,000 operational hours.
2) Produce 37-120 lumens/watt from the light source and ballast.
3) Reduced heat production and electricity usage.
4) Lower frequency of maintenance needed compared to traditional street lighttechnology.
5) Higher durability because they are mounted on a circuit board rather than beingmade of glass, instead[45-46].

Correlated colour temperature (CCT), mesopic vision brightness, dark adaptation, colour perception, fog penetration, and sky glow pollution are some of the crucial elements totake into account when assessing if an LED light is appropriate for use as street lighting. UnderLED streetlights with a CCT of about 3000°K, the human eye has respectable dark adaptationtime and colour discriminating ability. Roads can use LED light at this temperature since it has a relatively good luminous efficacy[47]. The design offers the uniform brightness level that isrequired by both cars and pedestrians. With maximum eye comfort, the LED can provide a light pattern that enhances the driver's visibility. Given the dangers of inattention and reduced vision at night, LED street lighting enhances safety for both motorists and pedestrians[48].

In several smart areas where the worldwide investment is anticipated to be approximately 53.6 billion dollars, LEDs are quickly taking over as the primary source of lighting in the future years. In addition to its many benefits over traditional lighting, LED lighting also has a number of drawbacks. They include the fact that performance and dependability are very temperature-sensitive, as well as the poor light coupling through the LED surface, which lowers the external quantum efficiency [49-50].

III. STREET LIGHT AUTOMATION

A. *Components Used*

S. NO.	COMPONENTS	SPECIFICATION
1	Arduino Uno	22 pins, operating voltage: 5-20 V
2	LDR sensor	Voltage: DC 3-5 V, 5 mm, 1.8 g
3	PIR motion sensor	Voltage: 4.5V to 20V, Range: 3-7meters, Angle: 110^0
4	Resistor	220 ohm, 10 kohm
5	LED	5 mm, operating voltage: 5 V
6	9V battery	Voltage: 9 V, weight: 45 g

IV. WORKING PRINCIPLE

As mentioned in the introduction, two parameters must be taken into account in this system. When ambient light levels fall below a specified threshold, for one, and when a personis detected, for another, the street light is turned ON [51-52]. LDR and PIR motion sensors are used for these tasks, respectively. LDR and PIR motion sensor interface with a microcontroller. Automatic street light control system activates and deactivates street lights in response to human detection and when ambient light levels fall below a predetermined threshold [53]. Using this system, we can cut the cost of manpower and unnecessary power consumption since the manpower needed for controlling the light consumes a significant amount of money. We also know that during day time there is no essence of street light this problem is solved by LDR sensor [54-57]. LDR sensor keeps the street light OFF in day time. When the light intensity is low then the LDR sends a signal to the microcontroller and in turn the light is switched on. PIR motion sensor detects the human presence and turns ON/OFF LED light, by controlling itssignal to the microcontroller [58-59].

A. Block Diagram

LDR and PIR motion sensors can be used as inputs in this block diagram, and either a street light or a lead can be used as an output[60]. The sensor can collect data from the outside environment and convey it to the microcontroller, in this case the Arduino Uno R3. The microcontroller processes the sensor data and acts on it in accordance with the input data. The brain or central component of the project is an Arduino board that can control sensors and lights[61]

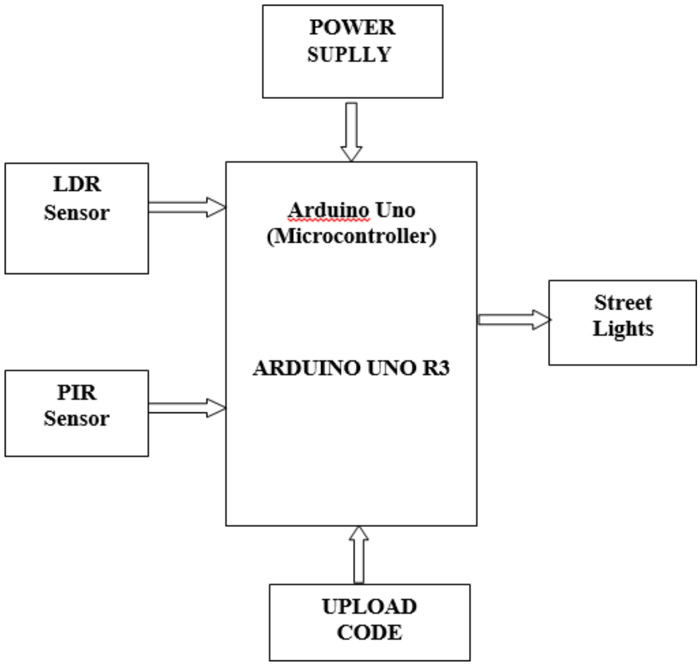

Figure 2 – Block Diagram of Street Light Control System using Arduino Uno[61]

V. SUPER - HYDROPHOBIC COATING

Coating is the process in which coating solution is applied on the surface of the object. Coating is done for two purposes, functional improvement of a material and for the decoration purpose[96]. Sometimes coating is done for specific body parts or throughout the body. Coating is applied to the material to improve surface properties or to change the functional properties that is wear resistance, adhesion, corrosion resistance and wet-ability.[87-88]

A. Overview of ZnO Nanoparticles Preparation and Coating

ZnO nanoparticles can be prepared with the help of Sol-gel process effectively. First of all the suitable precursor for the process is chosen and it is dissolved with solvents in a suitable proportion and a suitable stabilizer is added to the mixture as per a known proportion. The mixture is then stirred constantly at a pre-determined temperature for a specified duration. Then we obtain the Sol containing the ZnO nanoparticles [62].

The Sol can be coated directly on the substrate mainly by two methods
(i) Spin coating,
(ii) Dip coating. In spin coating method, the sol is placed on the substrate and the arrangement is rotated at a specific rpm. By this method the sol gets completely coated on the substrate and it is further taken to evaporation of solvents and heat treatment. Whereas in dip coating method, the sol is taken in a container and the substrate is dipped into the sol with a specific dipping speed, coating duration and the withdrawal speed [63-64]. By this method homogenous coating can be achieved on the substrate, then the specimen will be taken to evaporation of solvents and heat treatment to form dense films as shown in Figure 3(a).
If not coating directly after the Sol preparation, we can condense the sol particles by gelation and prepare the Gel. There after the gel can be converted into Xerogel by evaporating the solvents [65]. Then it can be subjected to further heat treatment to form a dense ceramic as shown in Figure 3(b).

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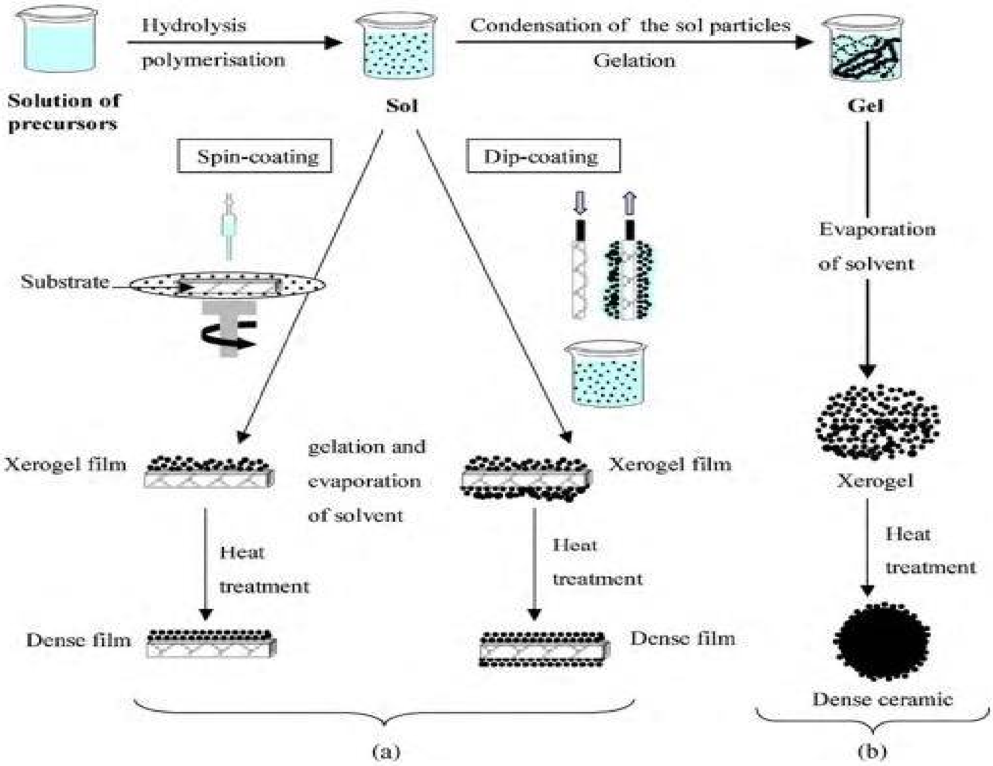

Figure 3 – Overview of ZnO sol-gel synthesis (a)Dense films formed by colloidal sol(b)Dense ceramic formed by the colloidal gel[65]

B. Sol-gel Synthesis of ZnO Nanoparticles

The solution of ZnO sol-gel is prepared by dissolving zinc acetate dihydrate (ZAD) (Sigma Aldrich 98%) in 30 to 50 mL of isopropanol (ISOP) (Merck), using monoethanolamine(MEA) as a 1:1 ratio solvent and stabilizer. This sol-gel solution is stirred at 75 °C for 1 hour and 30 minutes to achieve a homogeneous mixture[66-67]. ZAD acts as the source of zinc ions, while isopropanol serves as a solvent. MEA not only functions as a solvent but also helps stabilize the solution[68]. By stirring at the specified temperature and time, a uniform distribution of ZnO nanoparticles is obtained within the sol-gel solution, resulting in a stable and suitable composition for various applications[69-70].

C. Dip Coating

The three different stages of Dip coating are Dipping, Deposition and Evaporation or drying. As shown in the below figure, the substrate is first dipped completely into the sol at a predetermined speed and the sol is allowed to deposit on the surface of the substrate for some particular time and ultimately withdrawal of the substrate takes place and it is dried to removethe moisture from the obtained coating [71].

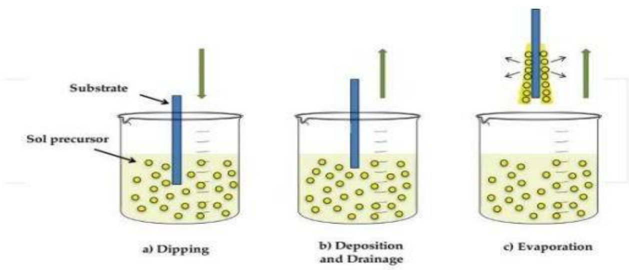

Figure 4 – Stages of Dip coating[32]

The clean glass substrates are then dipped into the ZnO sol-gel solution, ensuring complete immersion. After withdrawal, excess solution is allowed to drain off. The coated substrates undergo pre-annealing at 150°C for 10 minutes to remove solvents and enhance film adhesion[72-73]. Following each layer, the film is dried for 10 minutes at 150°C using a heater to evaporate any remaining solvents. This dip coating and drying process is repeated 10 timesto accumulate multiple layers of the ZnO sol-gel film on the glass substrates[91]. By following these steps, a uniform and multi-layered ZnO sol-gel film is obtained on the glass substrates. Such films find applications in areas like optoelectronics, solar cells, and sensors, benefiting from the desirable properties of ZnO films[74-75].

D. Heat Treatment

To enhance the properties of the ZnO film, a pre-annealing step was performed by annealing the coated glass substrates at 150 °C for 10 minutes[76]. This process promotes theformation of well-defined crystal structures, improves film crystallinity and enhances adhesionto the substrate. The pre-annealing step was repeated ten times, resulting in a dense coating ofZnO on the glass surfaces. Subsequently, annealing heat treatment was carried out at temperatures of 450 °C, 500 °C and 550 °C using a muffle furnace[77]. This additional annealing process allows for structural modifications and optimization of the ZnO film's properties, enabling customization according to specific requirements. The combined pre- annealing and annealing steps contribute to the formation of a high-quality ZnO film with improved characteristics[78].

E. Surface Morphology of the Coating

As shown in the below figure, the coating was observed with the help of SEM image analysis and it was found to be uniform and free from porosity, when the annealing temperaturewas 550 ^{0}C. The obtained coating was thick enough and was properly adhered to the glass substrate[79].

F. Optical Properties

Figure 7 displays the optical transmission spectra of the ZnO thin films as a function of Zn^{2+} concentrations that were observed between 200 and 800 nm. All samples have an average

In the modern world, weight reduction plays a very important role, which improves the overall efficient of the system, Attempts are made to improve the efficiency of the system by substituting the low denser material .[94]As the concentration ofthe precursor increased, the transmittances of ZnO films slightly decreased. The amount of thegrain boundary or the film thickness is typically what determines how transparent a ZnO thin film is. Lower thickness ZnO thin films exhibit higher transmittance, whereas ZnO thin films with numerous grain boundaries or small grain sizes exhibit higher optical scattering and lowertransmittance. As shown in Figure 7, the ZnO thin film created from the 0.1 M Zn^{2+} solution has the highest transparency and as a result, the decrease in transmittance[81].

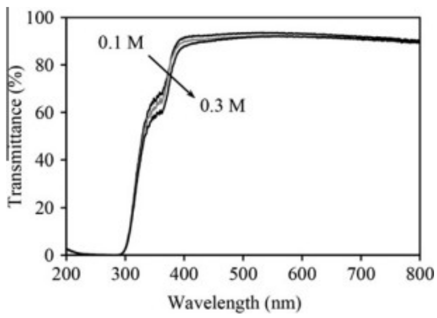

Figure 7 – Transmission spectra of the ZnO thin films at 0.1 M to 0.3 M[81]

Figure 8 displays the transmission spectra of the ZnO films. All of the films have highoptical transmission (>80%) in the visible region (450–800 nm), demonstrating the films' transparency in the visible spectrum. Due to band gap absorption, the transmission sharply decreases close to the ultraviolet region. For 0.05, 0.08, and 0.1 M sols, the absorption coefficient plotted in Fig. 4(b) demonstrates the presence of excitonic nature, which becomes more pronounced as the concentration rises. This is explained by the fact that strain lessens assol concentration rises[82].

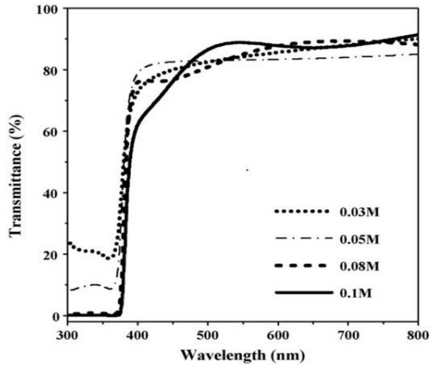

Figure 8 – Transmission spectra of the ZnO thin films at 0.03M, 0.05M, 0.08M to 0.1M[82]

VI. CONCLUSION

The current study showcases the importance of modern street light control system overthe traditional street lighting system. From the thorough analysis of all the research work carried out in the past, the conclusion can be drawn that the LED lamps are the best suited lamps for street light applications because of its reduced heat production, reduced electricity usage and increased working hours. The major goal of this study is to increase the system's efficiency by preventing unnecessary electricity loss during the day and while no one is there.Manual operation of the street lights can be avoided by the automation of the street lights and thus enhancing its working capabilities. The most cost-effective and secure method of reducing electricity usage is the suggested streetlight automation system. Our current world's problems with manual switching are eliminated, and most importantly, it makes it simple to reduce primary costs and maintenance. It lessens energy use that is not necessary. Using LDR and PIRsensors along with Arduino Uno, offers an effective and clever automatic streetlight control system.

The street lights can be made more effective with the help of ZnO coating on the surfaces of the casing of street lights. This helps in dust and moisture protection of the street lights and thereby resulting in efficient lighting. ZnO nanoparticles prepared by sol-gel methodat a precursor concentration of 0.1 M to 1 M, deposited on the silica glass substrates by dip coating process. The samples were first pre annealed at 150 ^{0}C for a duration of 10 mins and then again subjected to dip coating. After repeating the process for 10 times, annealing was carried at around 450 ^{0}C to 600 ^{0}C. These samples yielded better results. By the SEM image observations, it can be seen that the coating was deposited uniformly without any defects. Theresults shows that the grain size of the nanoparticles decreases with the increase in sol aging time. From the transmission spectra, conclusion can be drawn that more than 80% of the visible light of wavelength ranging from 400 nm to 900 nm penetrates the coating. As the precursor concentration increases, the coating exhibits better penetration to the light less than 300 nm wavelength.

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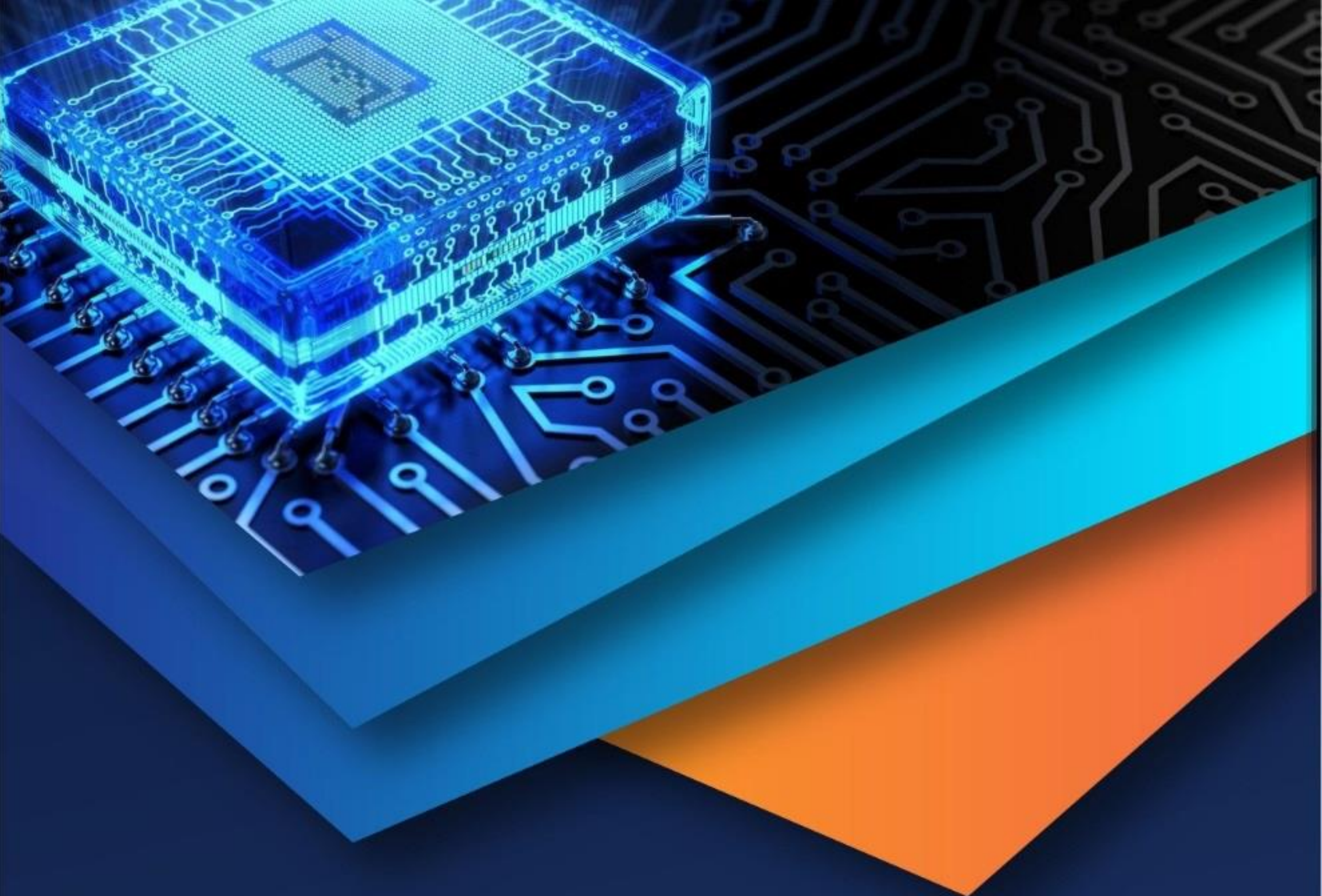

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