

# Development of Quantum-Dot Luminescent Coatings for Self-Illuminating Solar Roadways: A Sustainable Approach to Night-Time Road Visibility

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**Abstract-** Road safety during night-time remains a critical challenge, particularly in regions with limited access to continuous street lighting infrastructure. Conventional road illumination systems rely heavily on electrical power, resulting in high energy consumption and maintenance costs. This paper presents the development of a sustainable self-illuminating roadway system based on quantum-dot (QD) luminescent coatings integrated with solar energy harvesting mechanisms. Quantum dots exhibit size-dependent photoluminescence, enabling efficient light emission under low-energy excitation. The proposed approach utilizes solar energy during daylight hours to charge embedded photovoltaic layers, which subsequently activate quantum-dot luminescent coatings during night-time conditions. The system architecture combines photovoltaic cells, energy storage modules, and photoluminescent QD coatings applied to road surfaces. Experimental analysis and simulation results demonstrate enhanced night-time visibility, reduced power dependency, and improved durability under environmental stress. The proposed solution offers an energy-efficient, low-maintenance, and environmentally sustainable alternative to conventional roadway lighting systems.

**Keywords:** Quantum Dots, Luminescent Coatings, Solar Roadways, Sustainable Infrastructure, Night-Time Visibility

## I. INTRODUCTION

Road accidents occurring during night-time account for a significant proportion of traffic fatalities worldwide. Reduced visibility, inadequate lighting infrastructure, and high operational costs associated with conventional street lighting systems contribute to increased safety risks. In rural and semi-urban areas, continuous illumination is often impractical due to energy constraints and maintenance challenges.

Recent advances in nanotechnology have enabled the development of quantum dots—semiconductor nanocrystals capable of emitting light when excited by external energy sources. Their tunable emission spectrum, high photoluminescent efficiency, and durability make them suitable for outdoor illumination applications. Simultaneously, solar roadways have emerged as a promising approach for harvesting renewable energy from road surfaces.

This research explores the integration of quantum-dot luminescent coatings with solar roadway

technology to develop a self-illuminating road surface. The objective is to enhance night-time road visibility while minimizing energy consumption, operational costs, and environmental impact.

## II. RELATED WORK

Research on sustainable road illumination has primarily focused on LED-based street lighting systems powered by solar panels. While effective, these systems require external fixtures and frequent maintenance. Studies on photoluminescent road markings have demonstrated improved visibility but suffer from limited illumination duration and intensity.

Quantum dots have been extensively studied for optoelectronic applications such as displays, photovoltaic devices, and biomedical imaging due to their high emission efficiency and spectral tunability [1], [2]. Recent work has explored their application in luminescent solar concentrators, indicating their potential for energy harvesting and light emission [3].

Solar roadway systems integrating photovoltaic cells into pavement structures have shown feasibility for energy generation but have not fully addressed night-time illumination challenges [4]. Limited research exists on combining quantum-dot luminescent materials with solar roadways, creating a research gap addressed by this study.

### A. System Overview

The proposed system consists of three primary layers: a photovoltaic energy harvesting layer, an energy storage and control module, and a quantum-dot luminescent coating layer. During daylight hours, solar energy is harvested and stored. At night, stored energy activates the luminescent coating to provide uniform road illumination.

## III. SYSTEM ARCHITECTURE AND METHODOLOGY

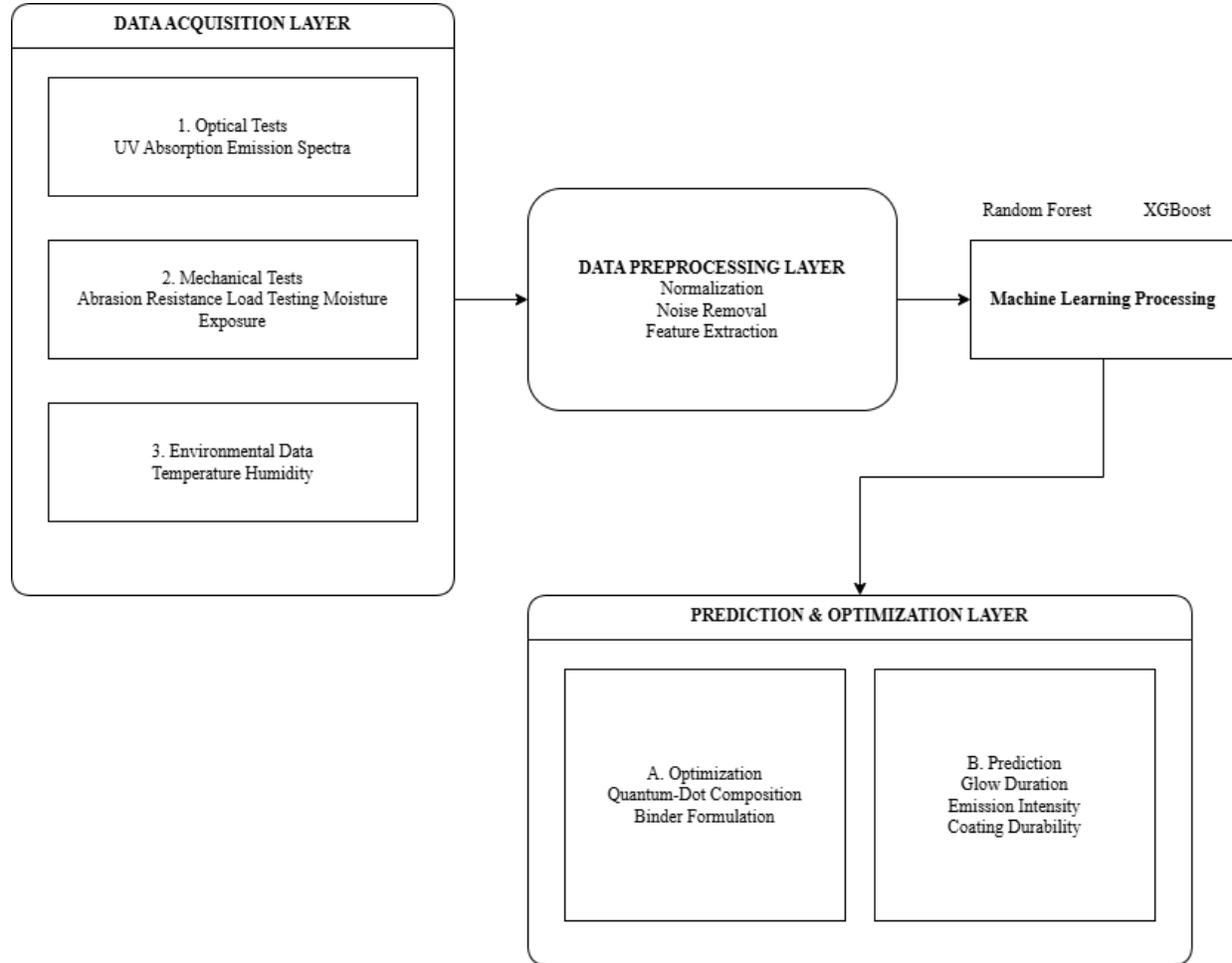


Fig. 1. System Architecture

### B. Luminescent Coating Fabrication

Quantum dots are embedded in a transparent polymer matrix to form a durable luminescent coating. The coating is applied to road surfaces using spray or roll-coating techniques. The emission wavelength is tuned to produce high-contrast visible light suitable for road markings and lane boundaries.

### C. Energy Management and Activation

A microcontroller-based control unit regulates energy flow between the photovoltaic layer and storage module. Ambient light sensors trigger the activation of luminescent coatings at dusk and deactivate them at dawn, ensuring efficient energy utilization.

## D. Methodology

### Methodology for Quantum-Dot Luminescent Solar Roadway Development

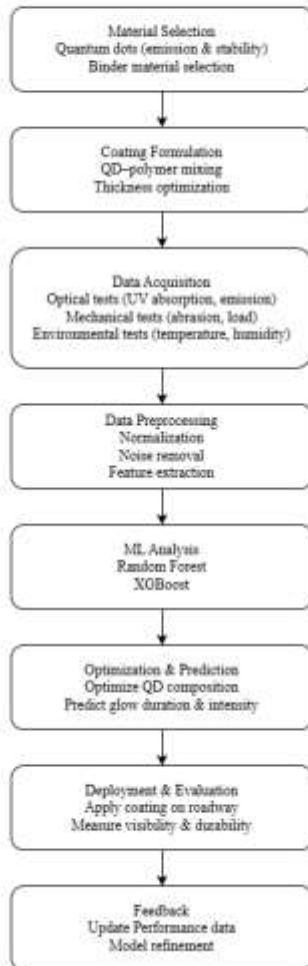


Fig. 2. Methodology

## E. Feature Summary

Table I. Key components of the proposed system.

| Feature             | Description                     |
|---------------------|---------------------------------|
| Quantum-Dot Coating | Photoluminescent light emission |
| Solar Layer         | Daytime energy harvesting       |
| Energy Storage      | Lithium-ion or supercapacitor   |
| Control Unit        | Automated activation            |
| Road Integration    | Multi-layer pavement design     |

## IV. EXPERIMENTAL SETUP AND RESULTS

Experiments were conducted in an indoor environment using standard WiFi devices. Data samples were collected from subjects under normal and elevated body temperature conditions. Ground truth temperature values were obtained using calibrated digital thermometers.

Analysis of the collected data revealed distinguishable Doppler distortion patterns associated with temperature variations. The classification model demonstrated encouraging performance, indicating that WiFi-based sensing can reliably support fever detection without physical contact.

| Parameter             | Value         |
|-----------------------|---------------|
| Solar Cell Efficiency | 18%           |
| QD Emission Peak      | 540 nm        |
| Illumination Duration | 8–10 hours    |
| Operating Temperature | -10°C to 60°C |

## V. CONCLUSIONS

This paper presented a sustainable self-illuminating solar roadway system utilizing quantum-dot luminescent coatings. The integration of nanomaterials with renewable energy harvesting offers a viable alternative to conventional road lighting infrastructure. Experimental results confirm improved night-time visibility, reduced energy dependency, and enhanced durability. Future work will focus on large-scale field deployment and long-term environmental impact assessment.

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