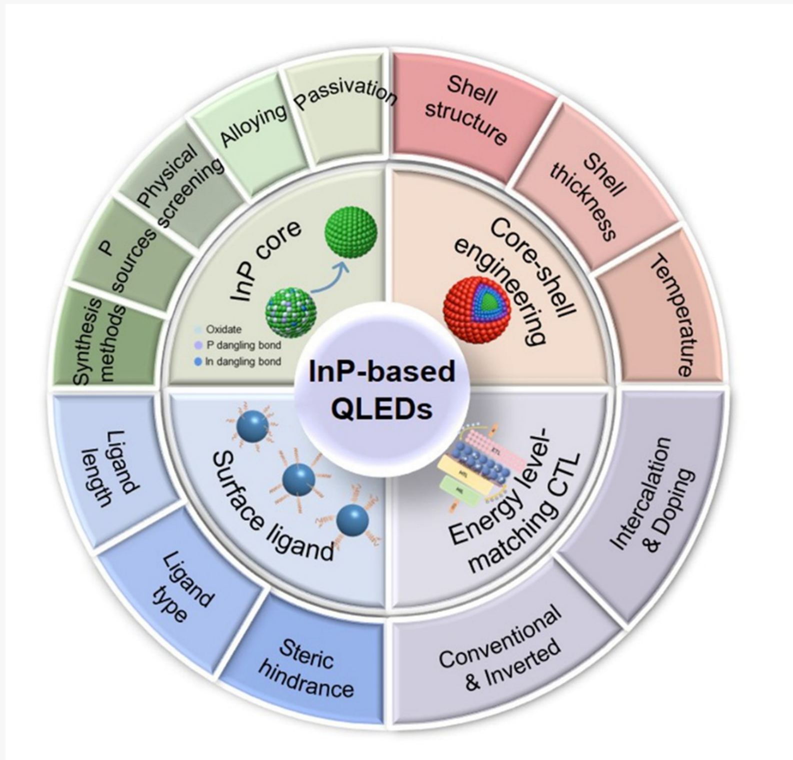
Challenges and Breakthroughs in Quantum Dots: From Nucleation to High-Performance QLEDs

Review analyzes InP quantum dots synthesis, core/shell optimization, ligands, and charge management for eco-friendly displays replacing cadmium systems



This diagram illustrates key strategies discussed in the review, from phosphorus sources and synthesis methods for indium phosphide (InP) cores to passivation, alloying shells, and ligand types, as well as energy level matching and interfacial doping in c

SHANNON, IRELAND, April 27, 2026 /EINPresswire.com/ -- Modern life is increasingly illuminated by displays and lighting technologies. Quantum dots are hailed as "star materials in the nano-world," with their unique quantum confinement effects and size-tunable optoelectronic properties demonstrating tremendous potential in these fields. The awarding of the 2023 Nobel Prize in Chemistry for the discovery and synthesis of quantum dots highlights the significant scientific value of this field. Among various materials, indium phosphide (InP)-based quantum dots stand out due to their non-toxic nature (free of heavy metals), broad spectral coverage, and excellent optical stability, making them ideal candidates to replace traditional cadmium-based quantum dots and drive next-generation green display technologies.

Despite their theoretically excellent properties, InP-based quantum dots face multiple challenges in practical applications. Achieving InP cores with uniform size, high crystallinity, and low surface defects remains a core challenge, as traditional synthesis methods struggle to precisely control nucleation and growth stages, leading to non-uniform size distribution, broad emission peaks, and low photoluminescence quantum yields—particularly with blue-emitting devices lagging significantly behind cadmium-based systems. Challenges in shell coating, surface ligand regulation, and charge injection balance further impact final photoelectric conversion efficiency and operational stability.

In a review article that was made available online on February 26, 2026, and later published in Volume 9, Issue 3 of the journal Opto-Electronic Advances on March 24, 2026, first author Yangyang Bian, from the School of Physical Science and Engineering, Beijing Jiaotong University, China, along with corresponding authors Dr. Chunhe Yang, Professor Aiwei Tang from the same institute, and Professor Fei Chen from the School of Nanoscience and Materials Engineering, Henan University, China, systematically summarizes the latest progress and challenges in performance optimization of InP-based quantum dots and the corresponding quantum dot light-emitting diodes (QLEDs). The review comprehensively analyzes nucleation mechanisms governing InP core formation and outlines strategies for core/shell structures, surface passivation, and ligand engineering.

Moving beyond the conventional "structure-property-application" listing approach, the review takes "nucleation kinetics" as its starting point and centers on "precise passivation of surface and interfacial defects," organically connecting controlled synthesis of InP cores, passivation of surface states, core/shell structure design, ligand engineering, charge injection, and leakage in QLEDs. It deeply reveals the intrinsic relationship between microscopic material properties and macroscopic device performance.

The review's value lies in its systematic integration of advances and clear delineation of research pathways for next-generation environmentally friendly display technologies. As the field of quantum dot materials transitions toward heavy‑metal‑free technology, InP-based technology—as the most promising commercialization candidate—directly impacts high-end displays, flexible electronics, and AR/VR applications. The in-depth analysis of charge injection balance, light-extraction efficiency, and blue-emitting device shortcomings promotes collaborative efforts to achieve high efficiency, brightness, and operational lifetime.

It can be anticipated that as the scientific issues outlined are addressed, InP-based quantum dots will replace cadmium-based materials in displays and play significant roles in solid-state lighting, bio-imaging, and photodetection, propelling optoelectronics toward a high-performance, low-environmental-impact, sustainable future. "This review provides a crucial scientific foundation for understanding and addressing the complex challenges in the synthesis and device integration of InP-based quantum dots," says Prof. Tang.

Reference
Title of original paper: Overcoming challenges in InP-based quantum dots: from nucleation mechanisms to high-performance quantum dot light-emitting diodes
Journal: Opto-Electronic Advances
DOI: https://doi.org/10.29026/oea.2026.250270

About Opto-Electronic Advances
Opto-Electronic Advances (OEA) is a rapidly growing high-impact, open access, peer reviewed SCI journal with Impact Factor of 22.4 (JCR 2024), which publishes top-quality original articles, letters and reviews covering significant research activities in optics and opto-electronics. OEA has been indexed in SCI, EI, DOAJ, Scopus, CA and ICI databases.
For more details, please visit the website: https://www.oejournal.org/oea/en/.

About Professor Aiwei Tang and Chunhe Yang from Beijing Jiaotong University, China
The research team led by Professor Aiwei Tang, including Dr. Chunhe Yang at Beijing Jiaotong University, has long been engaged in the study of quantum dot emitting materials and devices for next-generation display and lighting technologies. Their work encompasses the controllable preparation and luminescence performance regulation of colloidal quantum dots, the development of highly efficient electroluminescent devices, and quantum dot photolithography patterning technology. In recent years, the team has published over 160 SCI papers in journals such as Nature, Light: Science & Applications, and Nature Communications, and has obtained seven authorized national invention patents. The team has also led and completed multiple national and provincial-level projects.

About Professor Fei Chen from Henan University, China
Professor Fei Chen's team at Henan University specializes in research into InP-based quantum dot-emitting materials and electroluminescent devices. In the past five years, the team has published more than 10 SCI papers in journals including Nature, Nature Reviews Electrical Engineering, Nature Communications, Advanced Functional Materials, and Nano Letters. Professor Chen has led six national/provincial-level projects, including the China Postdoctoral Science Foundation and the Program for Science & Technology Innovation Talents in Universities of Henan Province.

Funding information
The authors acknowledge financial support from the National Key Research and Development Program of China [Grant No. 2022YFB3602901], Beijing Natural Science Foundation [Grant No. Z220007], the National Natural Science Foundation of China [Grant No.62574076], the National Key R&D Program of China [Grant No. 2023YFE0205000], the Zhongyuan High Level Talents Special Support Plan [Grant No. 244200510009], and the Technological Innovation 2030-Major Projects [Grant No. 2024ZD0604000].

Conor Lovett
Compuscript Ltd
+353 614-75205
email us here
