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Small-Pitch LED Display Technology Innovation Path and Commercial Value: From Technological Progress to Industrial Ecosystem Construction

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Abstract

This article explores the development of small-pitch LED display technology, analyzing its evolution and market applications from three dimensions: technological innovation, business models, and industrial ecosystem. On the technical side, optimizations in epitaxy and chip technology, advancements in mass transfer technology, and full-color solutions drive pixel pitch reduction to micron levels, enhancing display performance. Business models include vertical integration, specialized division of labor, and technology licensing, each adapting to different market needs. In the industrial ecosystem, Chinese enterprises form competitive advantages through patent accumulation and supply chain optimization, but face challenges in technical standardization and cost control. The study shows that small-pitch LED technology, through continuous innovation, is reshaping the display industry landscape and will expand applications in professional displays, commercial advertising, and other fields in the future, promoting a display era of higher resolution and more efficient performance. According to the 2025 market outlook, the Micro LED chip market is expected to grow at a compound annual growth rate of 93% to $744.7 million.

Keywords: small-pitch LED display technology, technological innovation, business model, industrial ecosystem, Micro LED, COB technology, mass transfer, full-color, vertical integration, specialized division of labor, technology licensing, market application, display performance

1. Introduction

1.1 Research Background

In the digital era, display technology is the root medium of information interaction, directly impacting daily life and work. From intelligent devices to high-definition public monitors, technical and innovative upgrades of display are constantly extending the user experience. Small-pitch LED display technology, because of its high brightness, high reliability, and versatility, is gaining popularity quickly in professional display, advertising, and conference markets. Technological advancement not only encourages industrial technological upgrading but also creates new business opportunities, promoting the transition from laboratory to market. At the exhibition of 2025 SID, Micro LED technology showed a remarkable development of improvement of performance and extension of application, such as Hisense's first consumer-grade 136-inch Micro LED display, marking a change of idea into commercialization. Apart from this, its prospects in high-definition display are usually recognized, especially in virtual reality and augmented reality applications, where its low power consumption and high brightness feature has special advantages, promoting the industry towards more sustainable development.

1.2 Research Objectives

This study aims to analyze the innovation path of small-pitch LED display technology and its commercial value. It focuses on how technological progress translates into market advantages, explores the application of business models and their impacts. By reviewing the development history, evaluating the pros and cons of models, and combining industry data, it provides decision-making references for enterprises to seize opportunities in competition. Specifically, it will identify key technical nodes, such as optimizations in mass transfer, and analyze their effects on cost and efficiency.

1.3 Research Significance

Theoretically, this study enriches the knowledge framework in the display technology field, providing new perspectives on innovation and commercialization. Practically, it offers references for enterprise strategic planning, investor evaluations, and policymakers, promoting sustainable industrial development. As Micro LED penetrates the mass market, this research can guide resource allocation and avoid blind investments.

2. Overview of Small-Pitch LED Display Technology

2.1 Technical Definition and Development History

Small-pitch LED display technology enhances resolution and visual effects by reducing pixel pitch. It was initially applied to outdoor large screens (pitch >10mm) and later expanded to indoor applications (4-10mm). After 2010, Chinese enterprises pushed the pitch to below P1.0, entering the micro-pitch era. COB technology has become mainstream, directly encapsulating chips on PCBs to improve protection and reliability, superior to traditional SMD. In 2025, companies like AET showcased innovations in COB and direct-view LED at the InfoComm exhibition, further expanding indoor applications. In the development process, Chinese manufacturers such as Leyard and Unilumin have dominated the growth of the small-pitch market, occupying over 70% of the global share (Qi, L. H. et al., 2021), driving the technology from outdoor to high-end indoor transitions.

2.2 Technical Advantages and Performance Comparison

Small-pitch LED outperforms LCD and OLED in multiple indicators. The following is a comparison based on the latest 2025 data:

Table 1.

Performance Indicator	Small-pitch LED	LCD	OLED
Brightness	5,000-15,000 nits	400~700 nits	600~1,200 nits
Contrast	>1,000,000:1	~2,000-5,000:1	>1,000,000:1
Power Consumption	25%-50% of LCD	Higher	40%-60% of LCD
Lifespan	>100,000 hours	50,000-80,000 hours	20,000~50,000 hours
Response Speed	Nanosecond level	Millisecond level	Microsecond level
Color Gamut	>120% NTSC	~72% NTSC	100%-140% DCI-P3 (~110% NTSC)
Plasticity	Extremely strong (spliceable, bendable)	Poor (fixed size)	Relatively Strong (bendable)

These advantages make small-pitch LED suitable for high-brightness environments, dynamic content, and flexible installation scenarios, such as XR virtual shooting and naked-eye 3D displays. As costs decrease, applications will further expand. Compared to LCD's backlight dependency, Micro LED's self-emission provides lower power consumption and higher brightness, suitable for outdoor and professional applications, while OLED matches in contrast but has a shorter lifespan. Additionally, Micro LED's lifespan advantage stems from inorganic materials, avoiding OLED's organic degradation issues, making it more reliable in long-term operation scenarios.

3. Analysis of Technological Innovation Path

3.1 Epitaxy and Chip Technology

Epitaxy and chips are the core foundation. Wavelength uniformity is controlled within ±0.5–1 nm to avoid color differences. EQE decreases with chip miniaturization (blue light ~70–80%, green light <50%), but can be improved to >60% through structural optimization. Defect density needs to be <10^8/cm² to ensure 4K yield >99.99% (Yu, J. C. et al., 2023). Companies like San'an Optoelectronics achieve these advancements through MOCVD optimization. In 2025, research introduced new chip structures, such as tandem Micro LED chips, to enhance TFT-based Micro LED display performance. Challenges from chip size reduction, including sidewall damage, are alleviated through advanced nitride-based Micro LED progress, driving displays toward higher ppi.

3.2 Mass Transfer Technology

Mass transfer is key to Micro LED mass production. Mainstream routes include stamp transfer (high precision but low efficiency), laser transfer (fast but high cost), and fluid self-assembly (low cost but poor precision). In 2025, progress focuses on high-yield and low-cost equipment, such as AUO's LTPS module integration, and simplified methods replacing metal bumps with photoresist bumps to improve connection efficiency. Other innovations include laser-assisted transfer and vacuum-based technology, aimed at accelerating commercialization. These technologies are classified into pick-and-place and emerging methods, balancing yield and cost, serving as the critical bottleneck from concept to mass production.

3.3 Full-Color Technology

Full-color relies on quantum dot (QD) conversion, elevating color gamut to 115–120% NTSC. Research shows that QD integration can improve efficiency and purity, suitable for high-end displays. In 2025, breakthroughs in QD color converters for Micro LED include microfluidic-based QD layers and microsphere-based green/red Micro LEDs, achieving EQE up to 40.8% and 22.1% (Zhang, X. et al., 2020). Additionally, photopolymerization creates 20-micron pixel QD microarrays, further improving conversion performance.

Table 2.

Technology Field	Full-Color Technology
Technical Name	Quantum Dot Technology
Color Gamut Improvement	To 115–120% NTSC
EQE Example	Green: 40.8%; Red: 22.1%

These advancements not only enhance color accuracy but also reduce power consumption, promoting AR display applications.

4. Business Model Innovation and Applications

4.1 Analysis of Mainstream Business Models

Business models include vertical integration (e.g., Samsung, share ~20–25%, gross margin ~28%), specialized division of labor (e.g., Leyard, leading in downstream share, gross margin ~25–30% (Wang, Z. et al., 2025); San'an, upstream share ~20%, gross margin ~12–35%), and technology licensing (high gross margin ~80–90%). Chinese companies like Unilumin and Absen lead in COB technology, occupying significant shares in the global small-pitch market. In 2025, China's LED display production accounts for 60% globally, with Shenzhen enterprises dominating.

Table 3.

Business Model	Market Share	Gross Margin	Fixed Asset Ratio	Licensing Income Ratio
Vertical Integration	25%	28%	Over 60%	-

Business Model	Market Share	Gross Margin	Fixed Asset Ratio	Licensing Income Ratio
Specialized Division(Downstream)	15-20%	25-30%	-	-
Specialized Division(Upstream)	20%	12-35%	-	-
Technology Licensing	-	80-90%	-	30-40%

Vertical integration provides supply chain control but is asset-heavy; specialized division focuses on strengths, improving efficiency.

4.2 Innovative Application Scenarios

In XR virtual shooting, LED walls can reduce costs by 20–40% and shorten cycles. Naked-eye 3D large-screen advertising premiums are 3–5 times higher. Conference all-in-one machines improve efficiency, with gross margins ~40–50% (Liu, Y. et al., 2025). In 2025, AWALL Vision's Micro LED TV showcased the most affordable option, promoting home applications. Additionally, in the digital signage field, Micro LED's durability supports smart city projects, expanding commercial potential.

4.3 Financial Characteristics and Valuation Differences of Business Models

Vertical integration: asset-heavy, net margin ~15%; specialized division: net margin ~18–20%; technology licensing: net margin ~35–40% (Kang, C. M. et al., 2025). Valuation indicators include P/E, P/S, and DCF. In 2025, intensified market competition and price wars compress profits, but innovations like Mini LED adoption rates exceeding 30% boost high-end product gross margins.

5. Industrial Ecosystem Construction and Competitive Landscape

5.1 Global Industrial Chain Structure

Upstream (chips): gross margin 30–50%, giants like San'an. Midstream (encapsulation): 20–35%. Downstream (displays): 25–45% (Chen, H. et al., 2025), leaders like Leyard. The overall market size in 2025 reaches $25.98 billion, with a CAGR of 5.72%.

Table 4.

Industrial Chain Segment	Gross Margin Range
Upstream	30%-50%
Midstream	20%-35%
Downstream	25%-45%

The industrial chain tends toward integration, with China dominating encapsulation and assembly.

5.2 Chinese Market Competitive Landscape

China's patent share is ~40–45%, with a growth rate of 37.5% (Anwar, A. R. et al., 2025), leading global increments. Leaders like Leyard have revenues exceeding RMB 1 billion, and Unilumin excels in segments. BOE and TCL stand out in Micro LED patents, driving local innovation. The competition presents a pyramid structure, with small and medium enterprises focusing on OEM.

5.3 Future Trends in Industrial Ecosystem

The future focuses on performance improvement, cost reduction, and intelligence. Applications expand to home and personal devices, with ecosystems tending toward integration. 2025 is a key year for Micro LED from concept to mass production (Lee, S. et al., 2025), with small-batch production starting. Cross-industry collaborations will become routine, such as alliances between semiconductor and home appliance enterprises.

6. Conclusion

6.1 Research Summary

Small-pitch LED technology enhances performance through innovation, reshaping the industry. Technological breakthroughs drive application expansions, and business models optimize market competitiveness. The maturity of the industrial chain will further reduce costs, promoting global adoption.

6.2 Research Limitations and Outlook

Limitations include insufficient analysis of user behavior and limited coverage of international markets. Future research can extend to policy impacts and technological integrations, such as AI-integrated displays.

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