

MICROLED DISPLAYS - MARKET, INDUSTRY AND TECHNOLOGY TRENDS 2021

Market & Technology Report - August 2021

Strong momentum for MicroLED with progress on all fronts. Cost is the biggest challenge, but Apple and Samsung are carving paths toward the consumer.

WHAT'S NEW

- Recent events and trends in technology and the competitive landscape
- Die size and cost roadmaps
- In-depth analyses of the microLED TV market: B2B vs. B2C, miniLED direct view LED display vs. microLED TVs
- Display drivers and architectures: TFT, microdrivers and chiplets
- Updated analysis of the microLED manufacturing and equipment emerging ecosystem: requirements, challenges, strategies, competitive landscape

KEY FEATURES

- Technology status: efficiency, transfer, driving, QNED, etc.
- Process flows
- Manufacturing, equipment
- Competitive landscape, key players
- Intellectual property trends
- Supply chain readiness, manufacturing, and equipment ecosystems
- Cost aspects, roadmaps
- MicroLED display applications: Strengths, weaknesses, opportunities, and threats (SWOT) analysis, roadmap and forecast for TVs, smartphones, wearables, automotive, augmented reality, laptops, tablets, and monitors
- MicroLED display panel and wafer demand forecast

A STRONG MOMENTUM: HAS MICROLED REACHED ESCAPE VELOCITY?

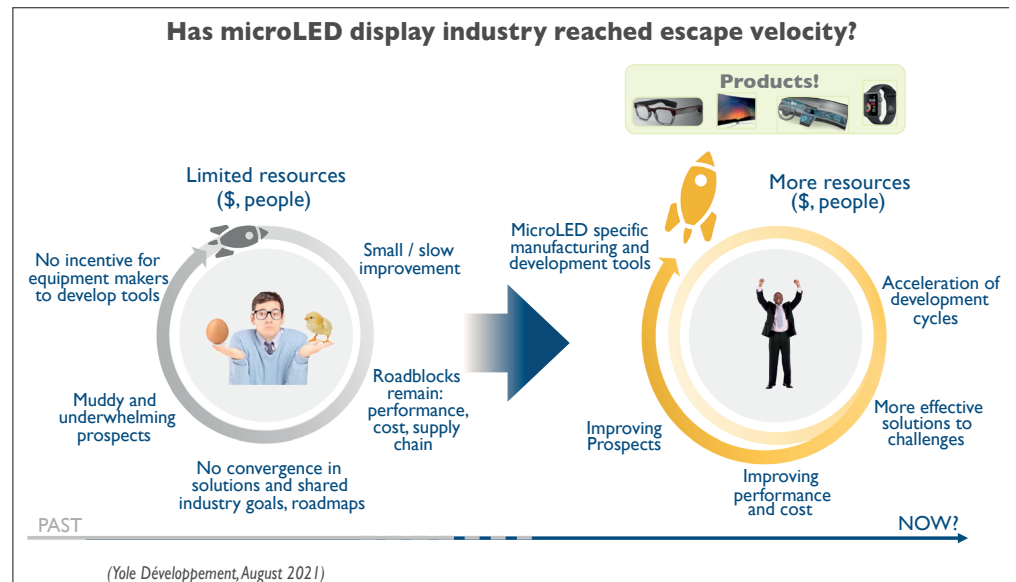
The current display industry environment is favorable to microLED: China won the LCD war, and the industry is turning its focus to technologies that deliver differentiation and high margins. Helped by a Covid-driven demand boost, it has swung back to profit and is generating cash to fund new technologies. While the LCD business model needs high-volume commodity products to absorb huge fab costs and make money on premium products, microLED could seed CapEx-light operations focused on serving premium markets.

Apple put microLED on the map when it acquired Luxvue. Display makers were initially skeptical but now believe that, while challenging, microLED displays might be credible contenders in some applications. As a result, money and resources are flowing into microLED, fueling a virtuous circle with faster developments, and improving prospects that are attracting further investments.

LCD or OLED didn't take off until HVM equipment became available. Equipment makers are now offering microLED-dedicated tools, and, although hindered by a lack of standardization in processes, some are developing one-stop solutions, including transfer, inspection, and repair.

Mass transfer is no longer considered a fundamental roadblock by most players. Many issues remain, but the industry now sees a clearer runway. Commercial tools from ASMPT, Toray, Coherent/3D Micromac using different processes are accelerating development. More are coming from TDK, V-Technology, Besi, Bolite/Contrel, etc.

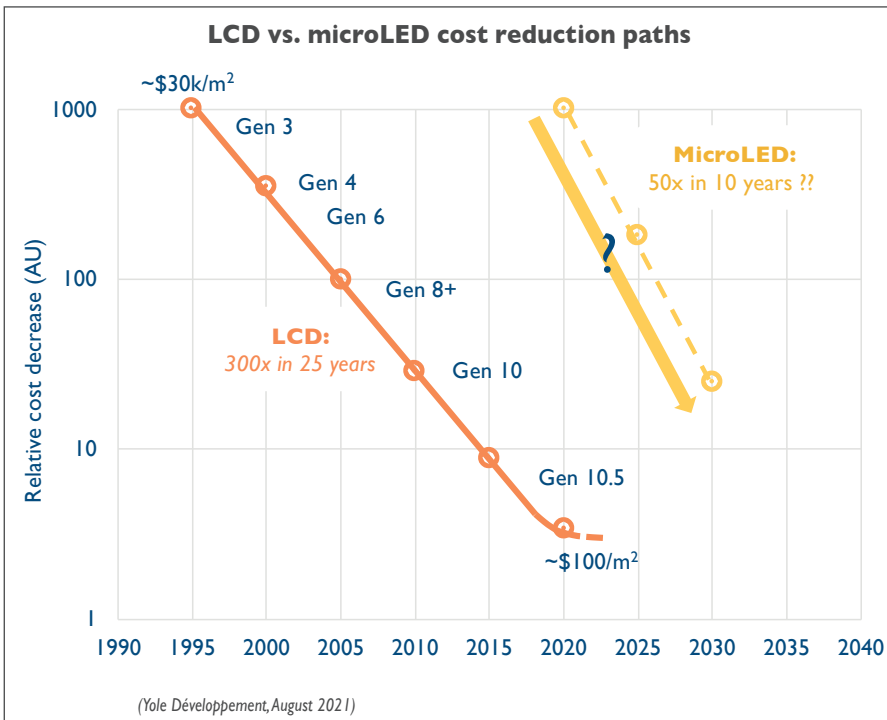
Samsung and Vuzix (with JB Display) are introducing the first commercial μ LED products in 2021. They won't yet move the needle of the display industry but are positive developments.



APPLE VS. SAMSUNG: EARLY SUPPLY CHAIN MOVES INDICATE DIFFERENT PATHS TO REDUCE COST

Strong momentum does not guarantee success: many technical and supply chain challenges could still derail microLED. Many solutions look great on paper, but real-life process integration in a high-volume manufacturing environment is much more challenging. Cost is the #1 obstacle and is still 20x to 50x too high for consumer products.

The cost of LCD decreased by a factor of 300, from \$30k/m² to \$100/m² in 25 years. However, LCD started from a blank canvas. Cost reduction opportunities lie across the board: materials, equipment, processes, etc. For LCD, the bulk of the decrease was achieved by generation scaling. MicroLED, on the other hand, exists at the



intersection of the mature Semiconductor, LED, and Flat Panel Display industries. Few contributors present 300x cost reduction opportunities, but in many cases, μ LED hasn't yet leveraged the technologies and wafer processing equipment that could help deliver significant improvements.

Apple clearly was aware of that: the company is driving its supply chain to a 200 mm wafer to unlock the fantastic efficiency of the mature Semi manufacturing philosophy that has remained untapped by the LED industry. This risky and initially costly bet could pay off, giving the company a unique advantage when it comes to addressing the smartphone market, which requires very small and low-cost yet high-performance chips.

Most other players are, for now, on the opposite path, building knowledge and reducing cost on existing 4" LED fabs while waiting for more clarity for the prospect of microLED. This approach could work for first products (B2B TV, etc.) or small displays but likely will not deliver the small die size and performance required for HVM of consumer TVs or smartphones.

PRODUCT ROADMAPS ARE COMING INTO FOCUS, AND THE SUPPLY CHAIN IS SHAPING UP

Many companies have some pieces of the microLED puzzle, but none has all of them. It is unlikely that any player will fully integrate all elements. Each will remain mostly focused on its core expertise: panel makers will source Chips-on-Wafer or binned, Chips-on-Carrier from LED makers. This leads to more margin stacking.

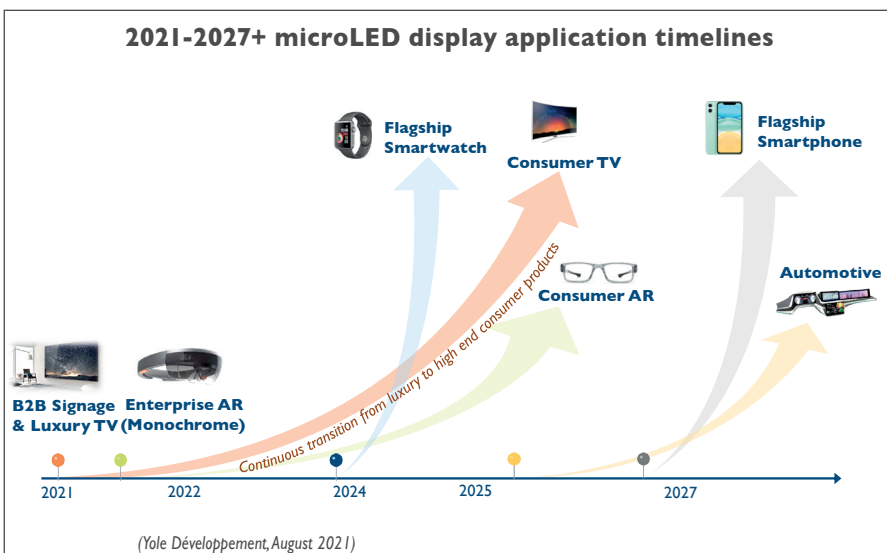
Collaborations are increasingly falling along nationalist lines: Chinese companies BOE, CSOT, Visionox, Huawei, etc., are collaborating with the major domestic LED makers Sanan, HC-Semitek, Nationstar, etc. At the same time, Taiwan leverages its strong LED, Display, and Semi ecosystem with AUO, Ennostar, and Playnitride increasing collaborations.

Is the trend driven by the COVID crisis what prevents teams from crossing borders? There are no major technology or equipment access

restrictions that would prevent fully national supply chains: microLED could become a supply-chain-decoupling poster child.

The traditional, vertically integrated display panel business model requires multi-billion-dollar fabs that few can afford. With microLED, the CapEx is distributed among different industries. This leads to a more complex but potentially more agile supply chain, opening the door to new entrants. If it desires, Apple could ultimately control a fabless μ LED display supply chain, independent of traditional panel makers and with multiple suppliers at each critical step.

For most applications, we are struggling to deliver a cost model scenario where microLED is significantly cheaper than OLED, let alone LCD. Strong differentiation is therefore essential. This is easier in segments with no strong incumbents. Adoption in Augmented Reality (AR) will take off from 2023, but AR is still searching for a strong use case for high-volume consumer adoption. Automotive is compelling for microLED, but long design and qualification cycles are pushing initial adoption beyond 2025. If Apple's current pilot effort succeeds, smartwatch will be the first high-volume consumer application with a product introduction anticipated for 2024. TV and smartphone are more difficult nuts to crack as OLED is a moving target, improving continually in both cost and performance. Samsung's commitment to TV is encouraging. The first real consumer products could emerge from 2025. Smartphone remains the most challenging application, but Apple's ambitious microLED technology choices bring new hope. Detailed forecasts of display and epiwafer volumes are presented in the report.



REPORT OBJECTIVES

Understand the status of microLED technology:

- Recent progress
- What are the remaining pinch points?
- Cost aspects, roadmaps

Competitive landscape and supply chain:

- Understand the microLED ecosystem: LED makers, equipment providers, panel makers, OEMs: key players, who does what, who works with whom?
- Scenarios for microLED display supply chain: OEMs, display makers, equipment makers, start-ups, and technology providers
- Impact on the display supply chain

Which applications could microLED displays address and when?

- Detailed analyses and roadmaps for major display applications
- Cost analysis



AUTHORS

Eric Virey is a daily contributor to the development of the Display activity at Yole, with a large collection of market and technology reports on display technologies, Quantum Dots, MicroLEDs, TFT backplanes as well as multiple custom consulting projects: business strategy, identification of investments or acquisition targets, due diligences (buy/sell side), market and technology analysis, cost modelling, technology scouting, etc. Eric has spoken in more than 50 industry conferences worldwide over the last 10 years. He has been interviewed and quoted by leading media over the world including: The Wall Street Journal, CNN, Fox News, CNBC, Bloomberg, Financial Review, Forbes, Technology Review, etc. He is also a regular contributor to various display industry media and organizations. Previously Eric has held various R&D, engineering, manufacturing and business development positions with Fortune 500 Company Saint-Gobain in France and the United States. Eric Virey holds a PhD in Optoelectronics from the National Polytechnic Institute of Grenoble. He is currently based in Portland, OR.

COMPANIES CITED IN THE REPORT (non exhaustive list)

3D Micromac (DE) Aixtron (DE), Applied Materials (US), Aledia (FR), Allos Semiconductor (DE), Advanced Powertch (KR), Aerotrans Tech. (TW), AMEC (CN), Apple (US), AQLaser (KR), ASMPT (SG), AUO (TW), Attolight (CH), BOE (CN), Bolite (TW), CEA-LETI (FR), Charm Engineering (KR), CIOMP (CN), Coherent (US), Comptek (FI), Contrel (TW), Compound Photonics (US), CSOT (CN), Cyberoptics (US), eLux (US), eMagin (US), Enkris (CN), ENNOSTAR (TW), EpiLED (TW), EpiPix (UK), Epistar (TW), Facebook (US), Flex Photonic (CN), Foxconn (TW), Gamma Scientific (US), glō (SE/US), GlobalFoundries (US), Goertek (CN), Google (US), GPM (TW), Hamamatsu (JP) and many more.

TABLE OF CONTENTS (complete content on i-Micronews.com)

Executive Summary	12	MicroLED Display Efficiency	240
Introduction to MicroLEDs	62	Color Conversion & RGB Chips	251
Cost Aspects	73	Transfer & Assembly	263
Forecast	79	Mass Transfer Metrics and Economics	270
MicroDisplays (AR, VR)	85	Mass Transfer Processes	277
TV and Information Displays	92	Mass Transfer and Assembly Equipment	293
Automotive	128	Yield Management: Inspection, Testing, and Repair	304
Smartwatch	142	Driving and Pixel Architecture	327
Smartphones	147	Self-Assembled Nanorod LEDs: QNED	343
Laptops, Tablets, and Monitors	155	Modular Display Tiling	355
Epiwafer Forecast	162	Monolithic Microdisplays	364
Intellectual Property Trends	168	Conclusion – What’s Next?	373
Recent Trends: The Shaping of the microLED Industry Landscape	183	Annex I: Recent MicroLED Display Prototypes	380
Competitive Landscape	200	About Yole Développement	385
Supply Chain	215		
Technology and Equipment	223		
Front End: Epitaxy and Chip Manufacturing	224		



Zine Bouhamri, PhD. Team Lead Analyst, Imaging & Display Activities at Yole Développement (Yole). Zine is managing the expansion of the technical expertise and the market know-how of the company. In addition, he actively assists and supports the development of dedicated imaging collection of market & technology reports and monitor as well as custom consulting projects. Prior to Yole, Zine oversaw numerous R&D programs at Aledia. During more than three years, he developed strong technical expertise as well as a detailed understanding of the display industry. He is author and co-author of several papers and patents. Zine Bouhamri holds an Electronics Engineering Degree from the National Polytechnic Institute of Grenoble (FR), one from the Politecnico di Torino (IT), and a Ph.D. in RF & Optoelectronics from Grenoble University (FR).

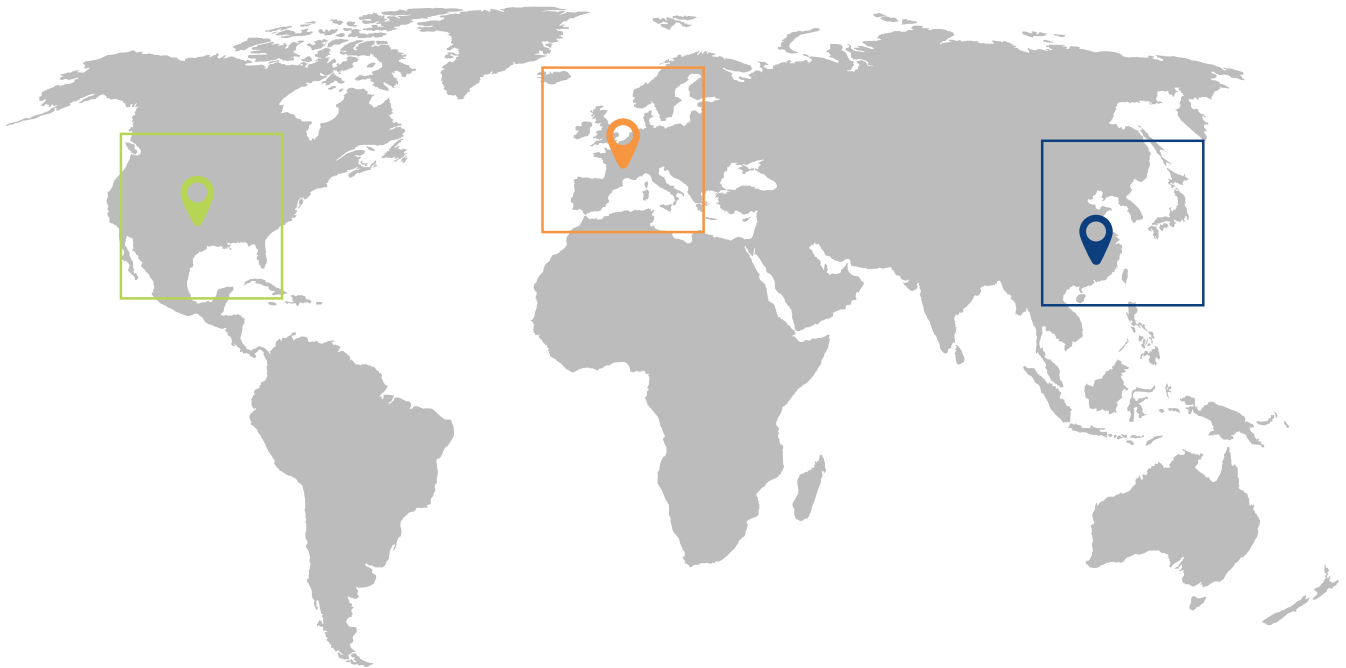
RELATED REPORTS, MONITORS & TRACKS



- MicroLED Displays - Intellectual Property Landscape and Analysis 2021
- Next Generation TV Panel Technology and Market Trends 2020
- Displays and Optics for AR & VR 2020
- Microdisplays – Market, Industry and Technology Trends 2020

More information and details about our offers and bundles opportunities on www.i-micronews.com

CONTACT



Western US & Canada

Steve Laferriere - steve.laferriere@yole.fr
+ 1 310 600-8267

Eastern US & Canada

Chris Youman – chris.youman@yole.fr
+1 919 607 9839

Europe and RoW

Lizzie Levenez - lizzie.levenez@yole.fr
+49 151 23 54 41 82

DACH (North Germany, Austria, Switzerland)

Neha CHAUDHURY - neha.chaudhury@yole.fr
+49 172 97 47 248

South Germany & France

Martine Komono - martine.komono@yole.fr
+49 173 69 43 31

Benelux, UK & Scandinavia

Marine Wybraniez - marine.wybraniez@yole.fr
+49 171 81 42 641

India and RoA

Takashi Onozawa – takashi.onozawa@yole.fr
+81-80-4371-4887

Korea

Peter Ok - peter.ok@yole.fr
+82 1040890233

Greater China

Mavis Wang – mavis.wang@yole.fr
+886 979336809 +86 136 61566824

Japan

Miho Ohtake – miho.ohtake@yole.fr
+81 34405-9204

Toru Hosaka – toru.hosaka@yole.fr
+81 90 1775 3866

Japan and Singapore

Itsuyo Oshiba – itsuyo.oshiba@yole.fr
+81-80-3577-3042

Sales Coordination & Customers Service

David Jourdan – david.jourdan@yole.fr
+33 472 83 01 90
Fayçal El Khamassi – faycal.khamassi@yole.fr
+33 472 83 01 95

ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

CONSULTING AND ANALYSIS

- Market data & research, marketing analysis
- Technology analysis
- Strategy consulting
- Reverse engineering & costing
- Design and characterization of innovative optical systems
- Financial services (due diligence, M&A)

More information on www.yole.fr

MEDIA & EVENTS

- i-Micronews.com website, application & related e-newsletter
- Communication & webcast services
- Events: TechDays, forums

More information on www.i-Micronews.com

REPORTS & MONITORS

- Market & technology reports
- Market and reverse technology quarterly monitors
- Structure, process and cost analysis and teardowns
- Cost simulation tool

More information on www.i-micronews.com/reports

CONTACTS

For more information about :

- Consulting & Financial Services: Jean-Christophe Eloy (eloy@yole.fr)
- Reports & Monitors: David Jourdan (david.jourdan@yole.fr) & Fayçal Khamassi (faycal.khamassi@yole.fr)
- Public Relations: Sandrine Leroy (sandrine.leroy@yole.fr)
- Marketing & Communication: Jean-Christophe Eloy (eloy@yole.fr)