Technical Report for Micro-LED Display

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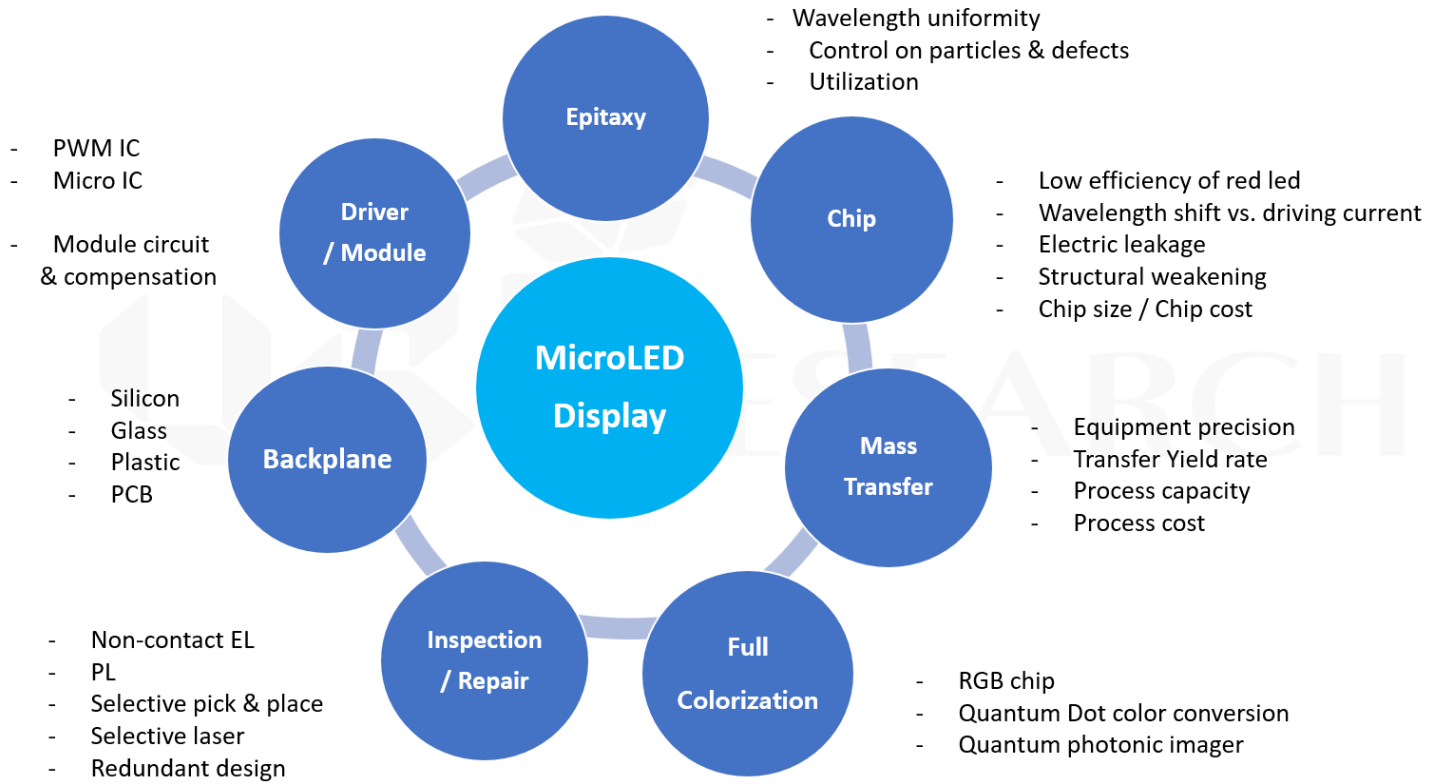
1. Analysis of Micro-LED technology

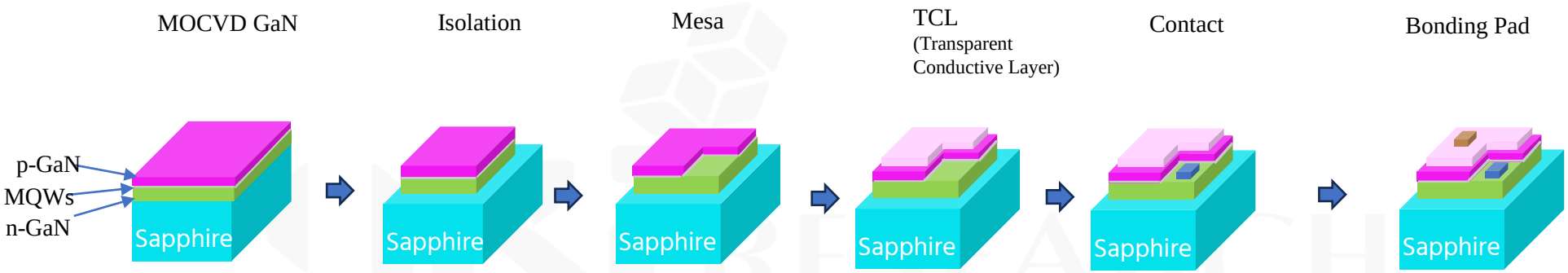
1.2 Basic core technologies of Micro-LED Display

- Micro-LED display technology can be classified into seven basic core technology groups as shown in the figure below. There are epitaxial technology, chip process, device structure required for LED chip production, Mass-transfer technology that transfers the manufactured chip to a display substrate, Inspection and Repair technology, colorization technology, backplane, and driving technology. For technology development competitiveness for the final product, it is important to develop linkage and cooperation among key technology suppliers related to each technology group.



1.4 The manufacturing process of GaN-based Micro-LED Chip

- The basic manufacturing process sequence of the GaN-based Micro-LED Chip is shown in the figure below.



- Proceed with the Epitaxial process using MOCVD
- an n-type layer, mulit-quantum well(MQWs), and a p-type layer are formed.

- The plasma etching process is used to etch the n-type GaN layer.
- Mesa Etching

- A transparent conductive layer (TCL) is formed on the upper surface.
- N Contact

- Bonding Pad Electrode Formation
- Passivation layer

1.5 Technical issues of the manufacturing process

- Wavelength uniformity

In general LED manufacturing, the wavelength change over the entire wafer should be within 4-12 nm, and the wavelength uniformity of micro-LED should be within 2 nm. The temperature difference of the wafer surface during the epitaxy process is managed within 1℃. The larger the size of the substrate, the more difficult it is to control the wavelength uniformity of the epitaxy process.

- Defects

It mainly includes particles, pollutants, scratches, etc. introduced from the environment or equipment during the chip epitaxial process. For particles larger than 0.8 mm in diameter, the defect density should be 0.1/cm² or less.

- External Quantum Efficiency

As the micro-LED size decreases, the external quantum efficiency at low current density rapidly decreases, mainly because sidewall damage due to plasma etching during manufacturing causes efficiency reduction and leakage current.

- Chip architecture
  - A structure of controlling the sidewall current by reducing the area between the contact resistance layer and the semiconductor layer was proposed. (CN102945268.A/patsnap)
  - The active layer of the sidewall portion is thinner than the active layer of the flat portion. Greater resistance and energy barriers of the sidewall portion reduce the sidewall leakage current. (US10968898B2/Lumileds)

- Chip manufacturing process
  - Instead of plasma etching, thermochemical etching is used to avoid sidewall etching damage.
  - Use the ALD process to protect the Micro-LED sidewall. (US20210193871A1)
  - A sidewall etching process is unnecessary by forming a P-type doping region in the N-type layer and forming a P-electrode to allow current to flow through the light emitting layer through the tunnel effect. (US11830966B2/PlayNitride)
  - GaN nanowire is grown in the opening area of the insulating layer, and a P-type semiconductor layer covering the nanowire and an upper electrode are sequentially formed. An electrode may be formed without etching the semiconductor layer. (EP3470360B1/Seoul)

2. Development status for Micro-LED display applications

2.1 Micro-LED Display Application Trend

- The glass substrate instead of the PCB substrate can be applied for high-quality products and the size of the LED chip gradually decreases to reduce costs and achieve high PPI. In conjunction with such a technical direction, more display exhibits for automobile applications and large transparent display prototypes aimed at commercial markets such as museums and aquariums have recently been introduced.

	Mini-LED on PCB	Mini-LED on Glass	Micro-LED on Glass				Micro-LED on Silicon
Application Field	Giant Screen/ Commercial Display	Commercial Display/ Large TV	Large TV	Automotive	Smart Watch	Smart Phone	AR
Potential Advantage	Spliceable, High brightness, Long lifetime		Spliceable, High brightness, Long lifetime, High image quality	Long lifetime, High reliability, Transparent, Flexible, Splicing	High brightness, Low power consumption	Sensor integration, Low power consumption	Small size, High resolution, High brightness
Typical Size	Customization	162”	89”	12.3”	1.78”	6.5”	< 0.2”
Typical Resolution	Customization	3840x2160	3840x2160	1920x720	368x448	2688x1242	> 2500x2500
Chip Size	60~300 μm		6~60 μm				1~8 μm
Typical PPI	25	27	50	167	326	458	> 3000
Driving Architecture	Micro-IC	Micro-IC / TFT	TFT				CMOS

3. Development status of Micro-LED display major companies

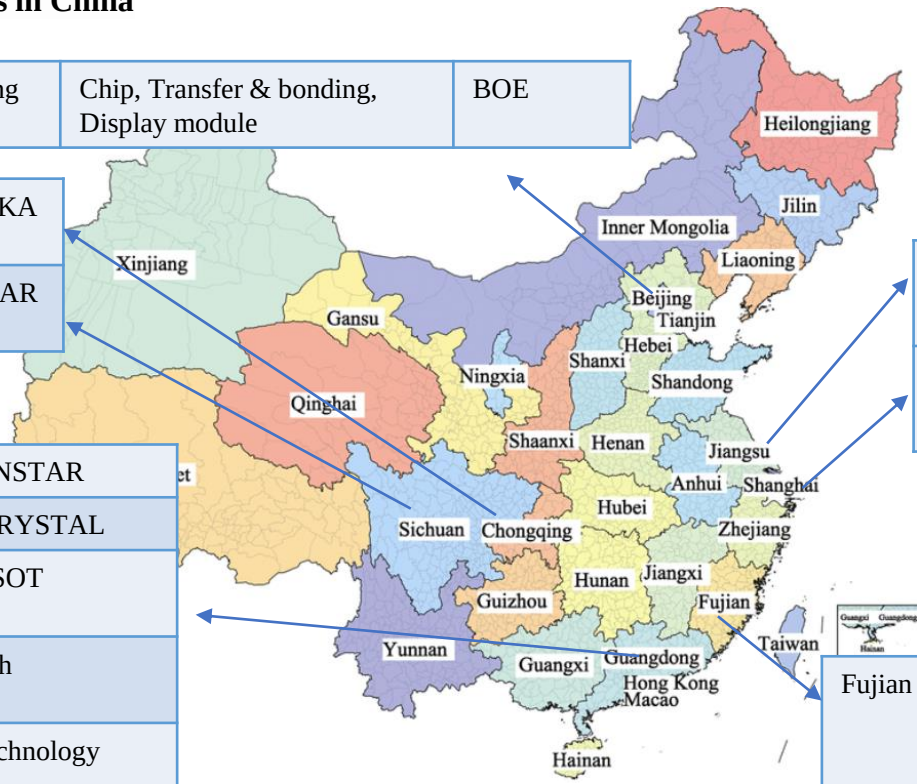
3.1 Development status by Chinese companies

❖ **Major companies and research institutes in China**

Beijing	Chip, Transfer & bonding, Display module	BOE

Chongqing	Chip, Transfer & bonding, Display module	KONKA
Chengdu	Transfer & bonding, Display module	VISTAR

Guangdong	Epi wafer, Chip	NATIONSTAR
	Epi wafer	SINO CRYSTAL
	Chip, Transfer & bonding, Display module	TCL/ CSOT
	Transfer & bonding, Display driving	SUSTech
	Transfer & bonding, Display module	HCP Technology
	Display Module	HUAWEI
	Display module	Sitan Tech.
	Display module	Tianma



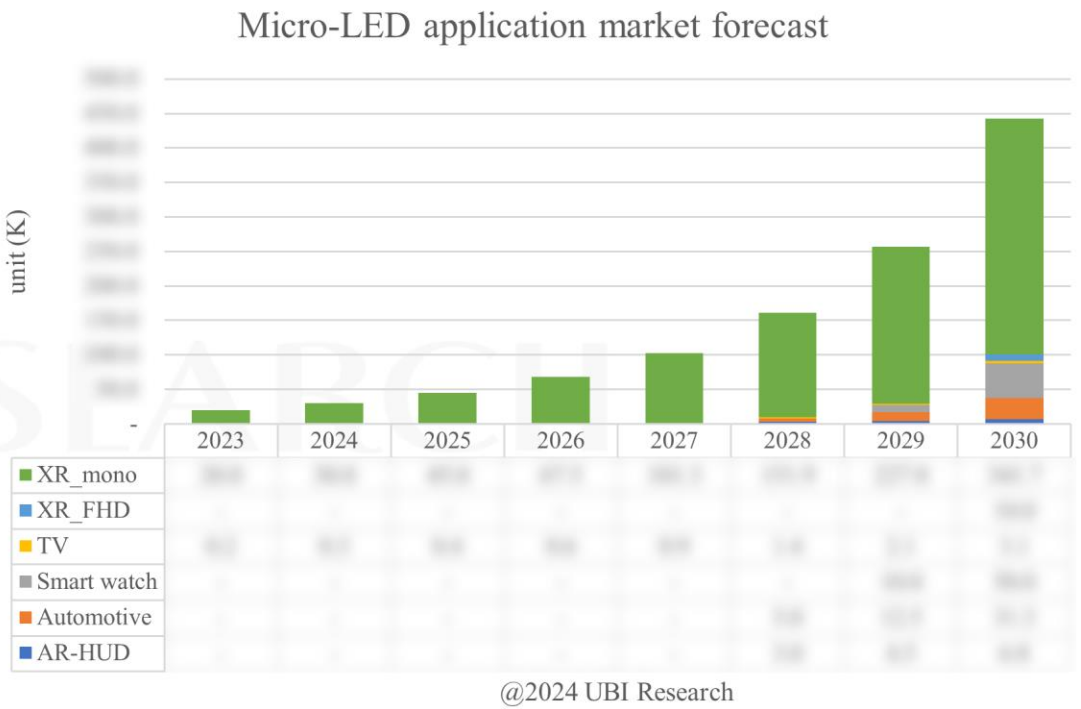
Jiangsu	Epi wafer, Chip	Enkris Semiconductor
	Epi wafer, Chip	BOE-HC SemiTek
Shanghai	Display module	JBD
	Chip, Transfer	CHIPFOUNDATION

Fujian	Epi wafer, Chip, Transfer & bonding,	SanAn Optoelectronics
	Epi wafer, Chip	CHANGLIGHT
	Chip, Transfer & bonding,	Fuzhou Univ.

5. Micro-LED Display Market Outlook

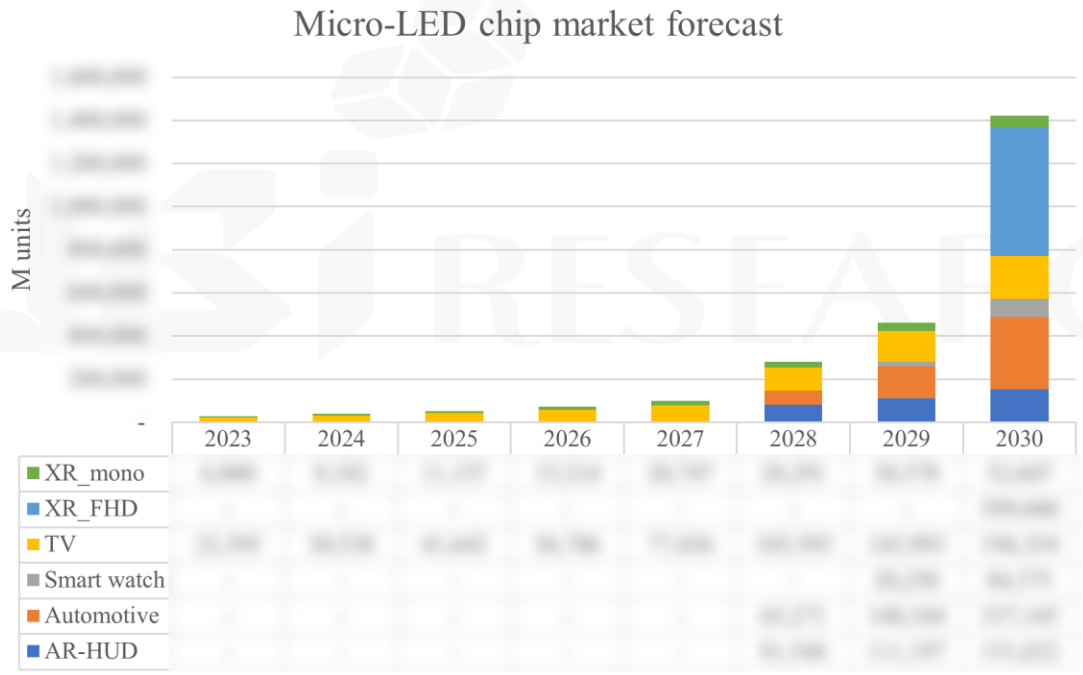
5.1 Market Outlook for Micro-LED Application Products

- Among the application products using Micro-LED, currently on the market are Micro-LED TVs and AR glasses using mono-color LEDs.
- Micro-LED TVs are sold by Samsung Electronics and recorded sales of *** units in 2023. Mono-color AR glasses are the main products using green LEDs, and several companies are releasing them.
- Micro-LED chips for FHD-class AR glasses are ultra-small with a size of 1μm, making it difficult to produce products with the company's current technology. The market is expected to open around 2030.
- Apple planned to produce a micro-LED smartwatch, but it is expected to be available for sale after 2029 due to a delay in achieving the target cost and process technology.
- The use of micro-LED is most certain for AR-HUDs for automobiles that require high-brightness displays. AR-HUDs are being actively introduced by all automakers as the next generation of HUDs.
- However, LCD and OLED are already in the market for dashboards, so it is expected that it will take time to enter the micro-LED market. Currently, the problem with micro-LED displays is yield. Therefore, since it is 5 to 10 times more expensive than OLED, the market is expected to start after 2028, when a yield above ***% can be achieved.



5.2 Market Outlook for Micro-LED Chip

- The graph shows the micro-LED application product market described in Chapter 5.1, the number of micro-LED chips required for display manufacturing, and the micro-LED chip market calculated by reflecting the yield of each product manufacturing process.
- Micro-LED chips are the most commonly used in Micro-LED TV products, but the market is still only in the *** because they are expensive products exceeding $100,000.



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