마이크로 LED
산업 및 기술동향

2019. 06. 21

Korea Photonics Technology Institute

μLED Display & Convergence Research Lab.

Chief Researcher
Y.W. Kim, Ph.D.

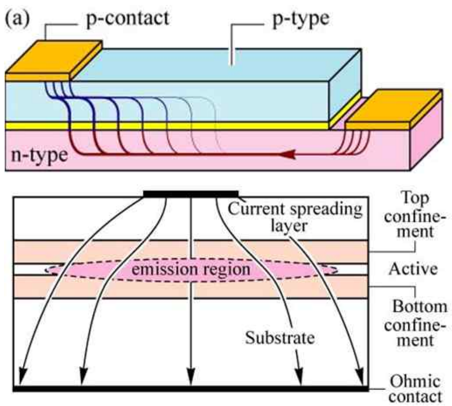
01 개 요

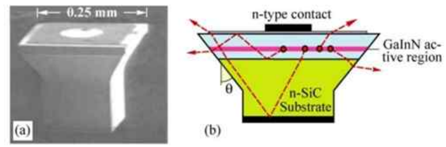
마이크로 LED

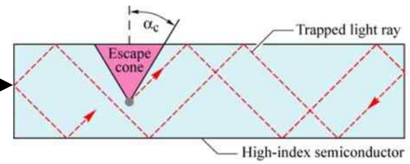
Efficacy Factor

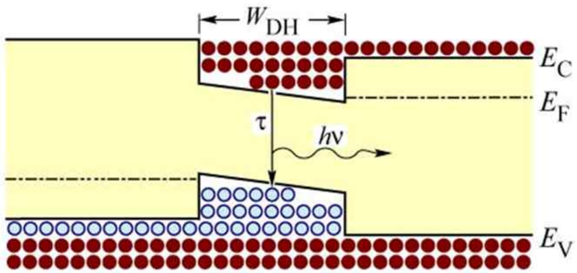
Epitaxtial Chip

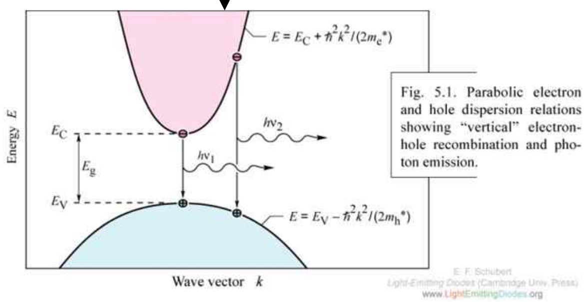
External Quantum Efficiency $= h_{injection} \cdot h_{internal} \cdot h_{extraction} \cdot h_{PKG}$

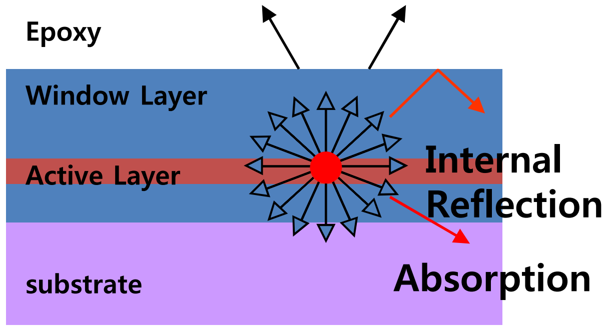










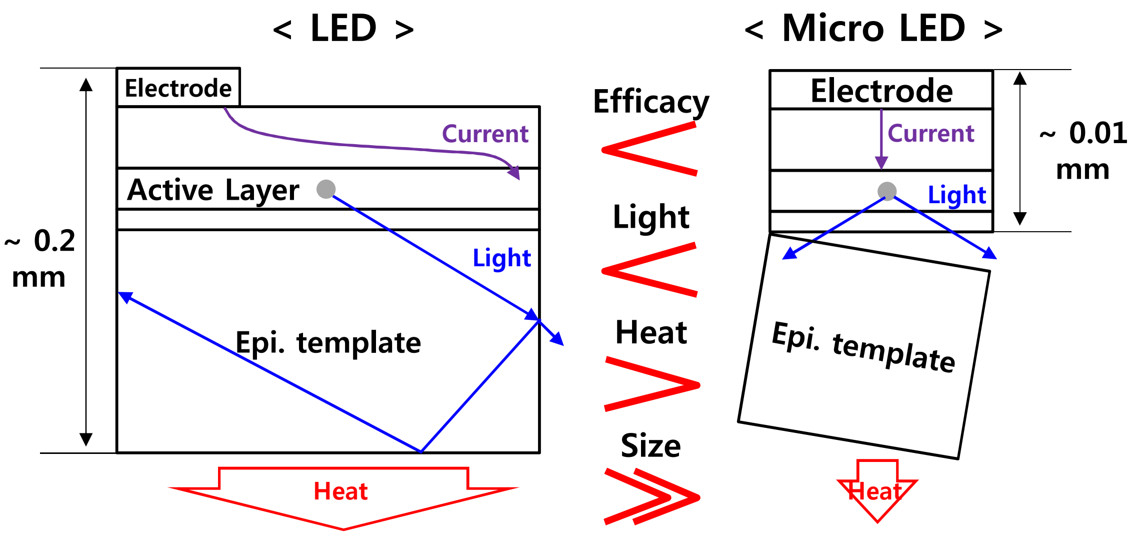


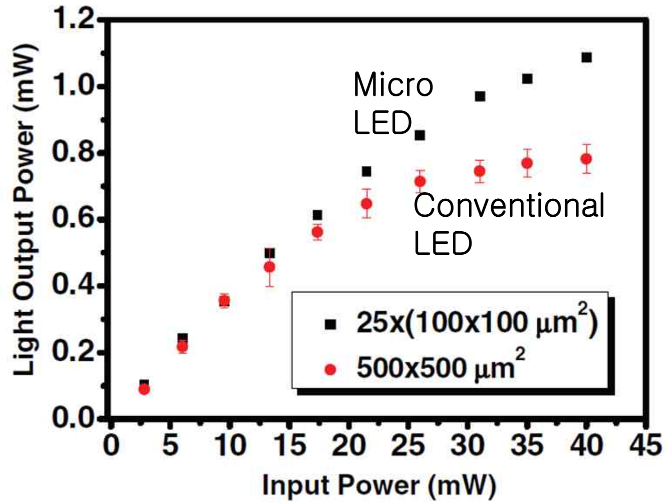
01 개 요

마이크로 LED

Higher Efficacy

- In the case of the conventional LEDs, the ray from the active layer is partially trapped in transparent sapphire substrate due to being out of an escape cone
- The extraction efficiency of Micro LEDs can't help being increased because of elimination of the epitaxial template, and also the lower stress of the epi. layer in processing the separation contributes to the higher efficacy
- The micro LEDs are extensively assembled on the PCBs or Backplane, and the lower heat flux in some area result in the improvement of the thermal effect



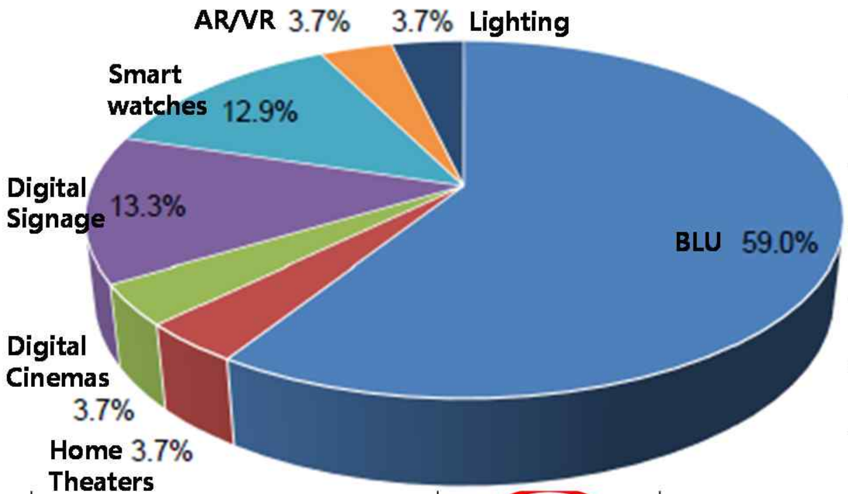


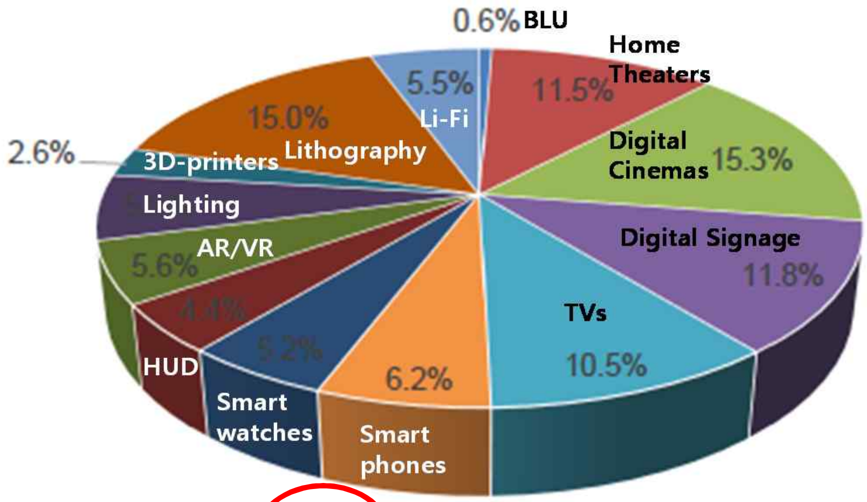
Reference : T.Kim, et.al., "High-Effi ciency, Microscale GaN Light-Emitting Diodes and Their Thermal Properties on Unusual Substrates" small 2012, 8, No.11, 1643~1649

02 국내외 시장동향

마이크로 LED

- **`18년 5억불 규모의 시장이 형성, 연평균 58.0% 이상 성장률로 `27년 714억불 이상의 시장으로 확대 예측**
  - **대형 디스플레이 신규시장은 건축물 내외장, 회의실, 상황실, 대강당 등**
    - ➢ 기존 LED 광고판의 누적설치 시장은 200조원 이상으로 추산, AM방식으로 50% 이상 전환 예상
  - **초소형 디스플레이는 야외에서 활용이 가능한 고휘도 저전력 제품에 적용**
  - **중소형 디스플레이는 스마트워치, 스마트폰, 자동차용 HUD 등에 `22년 이후 본격적으로 적용**
  - **Emerging Market 분야는 자외선 및 적외선 파장대역의 마이크로LED를 적용하여 반도체/디스플레이 생산장비 후방산업과 의료/바이오, 통신, 3D 프린터 등에 다품종소량 맞춤형 생산 형태로 발전 예상**

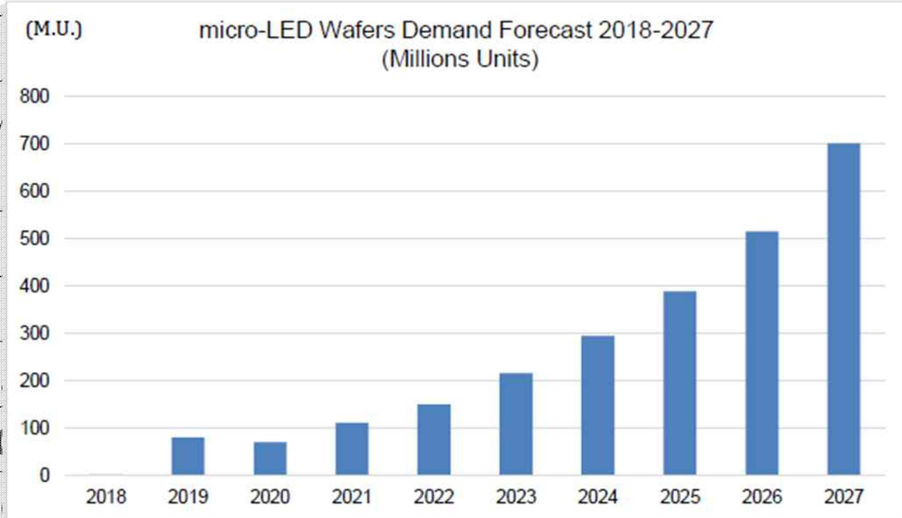


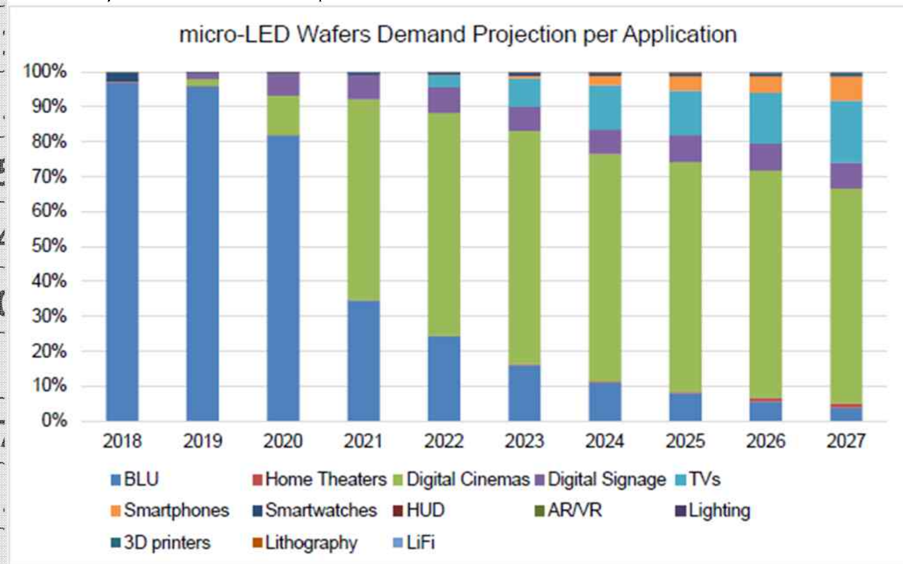


소계	5.0	34.6	100.6	322.2	713.4	58.0%

02 국내외 시장동향

	'19		
	Penetration Rate (%)	Shipments (millions)	Penetr Rate
BLU		20	
Home Theater	0.1	0.01	13
Cinemas	0.06	0.1	6.
Digital Signage	0.24	2	2
TVs	0	0	7.
Smartphones	0	0	5.
Smartwatches	11	5	81.
HUD	0	0	4
AR/VR/MR	9	1	7
Lightings	0.2	1	1
Lithography		0	
3D Printers	0	0	3
Li-Fi	0	0	18.



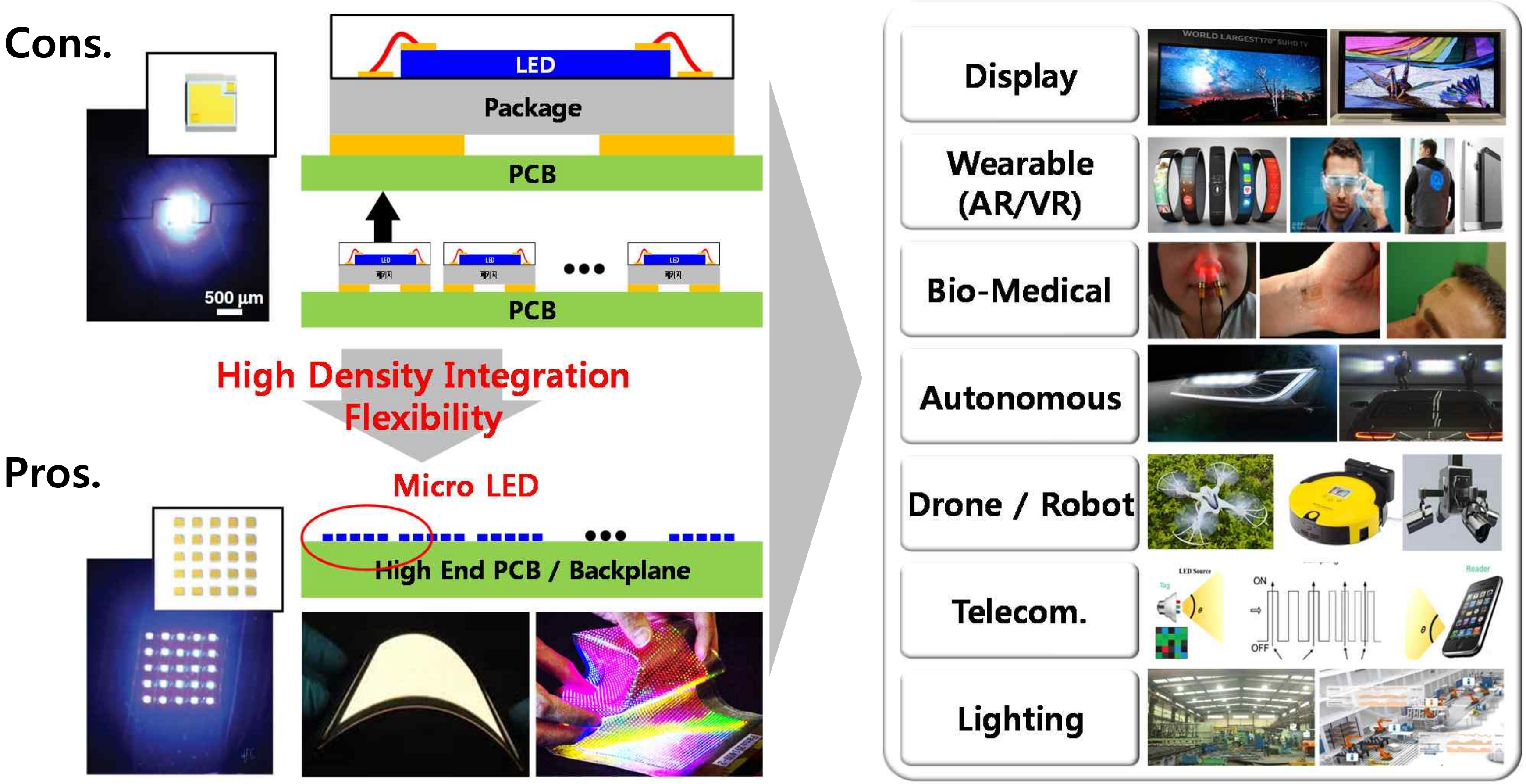


* Reference : n-tech Research Report, Micro-LED Market Opportunities: 2018-2027

02 국내외 시장동향

Applications : Display, Automotive, Lightings

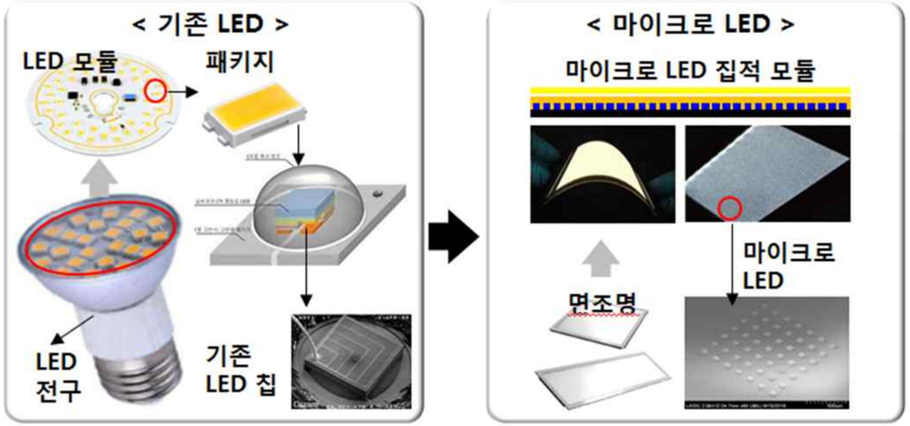
- **Core Technologies of Micro LED are compatibly Not only microminiaturization, but also Integration & Flexibilization for applications**



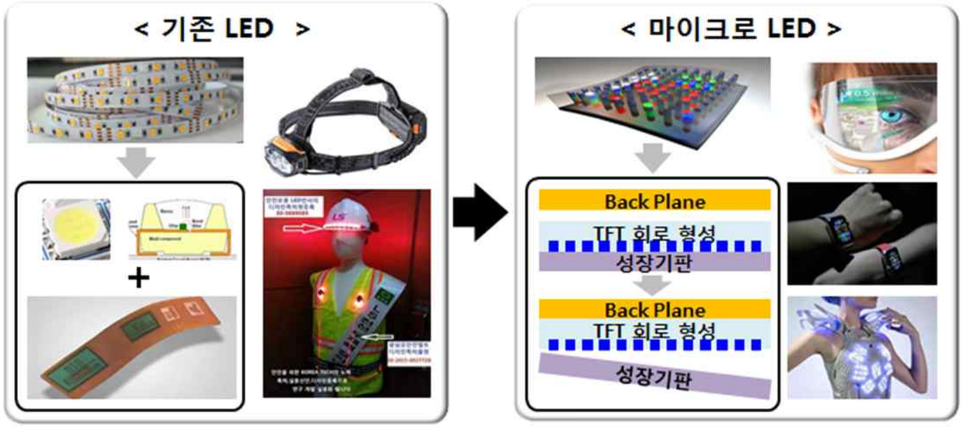
02 국내외 시장동향

마이크로 LED 융합

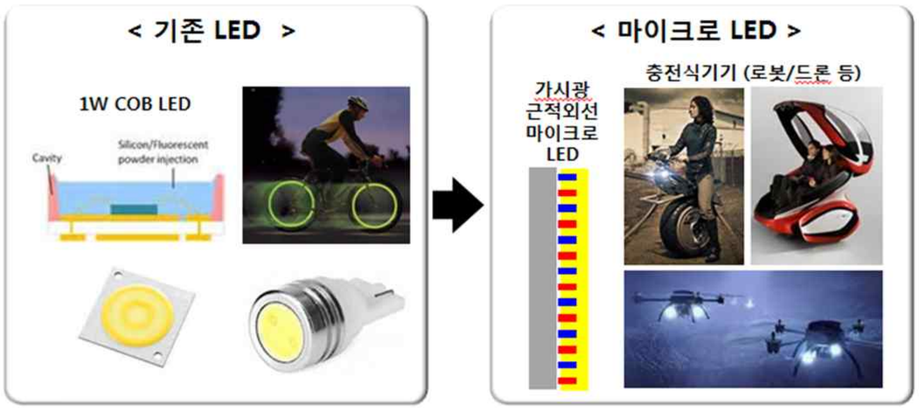
[Lightings]



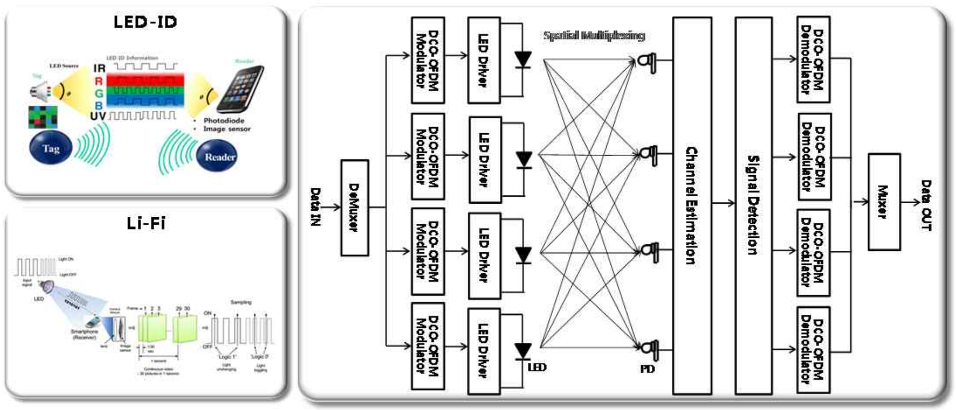
[Wearable]



[Drone/Robot]



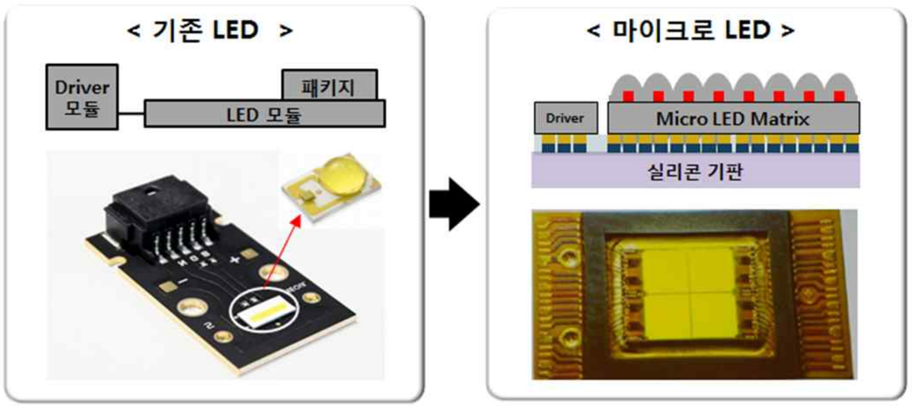
[Telecom.]



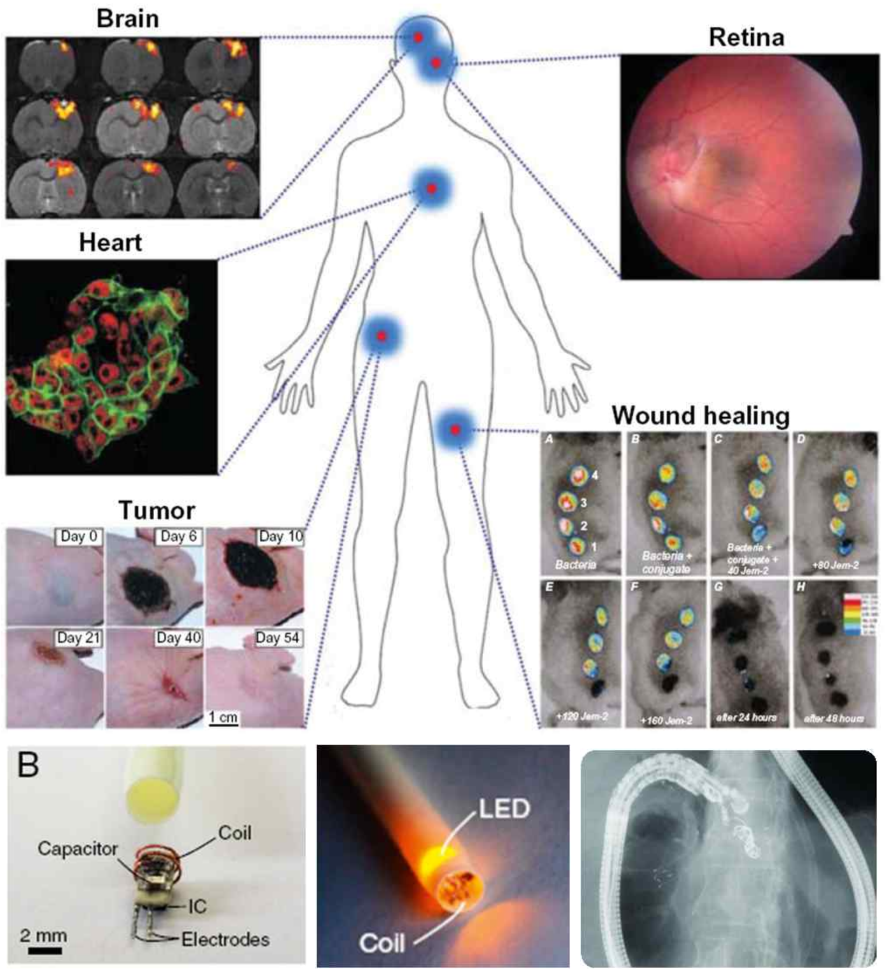
* Reference : n-tech Research Report, Micro-LED Market Opportunities: 2018-2027

마이크로 LED 융합

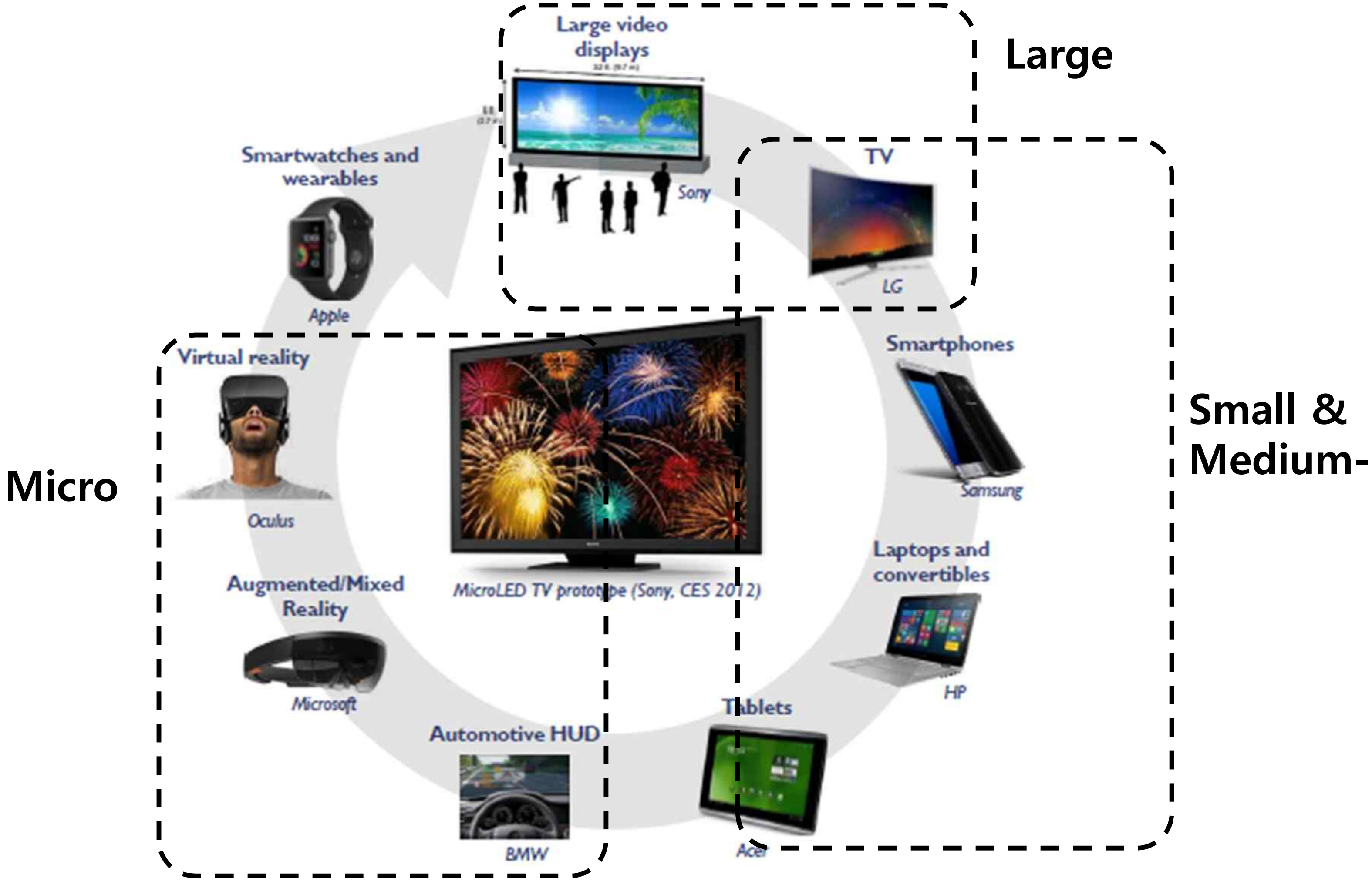
[Automotive – Headlamp, Lidar, Sensor]



[Bio. / Medical]



마이크로 LED 디스플레이



02 국내외 시장동향

초대형 디스플레이

세계최초 적색/녹색/암갈색 LED 적용

- 1982년 일본의 아카미전기(현 JR 히카시닛폰)가 나리타역 호텔에 설치, 1993년 이후의 RGB 삼원색 LED 디스플레이 출시에 이르기까지 구동방식 및 제어회로 개발이 활발히 이루어졌음

RGB 삼원색 기술적용

- 니치아화학공업과 비스미디어와 공동으로 1994년 12월 후쿠이시에서 대형 영상사업을 하는 차량탑재형 영상장치(라이저울스)를 개발
- 오사카와 도쿄 빌딩 벽면에 대형 Full-Color LED영상을 설치한 미디어기켄과 아카미전기가 1995년 3월 도쿄 시부야 역에 영상제어기술의 성숙도를 높인 대형 빌보드를 설치 → 산업화 입증
- 미쓰비시, 마쓰시다 등의 대기업들과 미국, 유럽 및 한국 등의 기업들의 시장참여가 가속화

[슈퍼라이저 (아카미전기, 1995년)]

[11.2m × 66.4 m 터프비전 (미쓰비시, 2006년)]

초대형 디스플레이

[Christie Velvet : MicroTiles]

[Mitsubishi 4K ChromaVision]

[Samsung SUHD 170" TV]

[Leyard 0.781 mm Pitch]

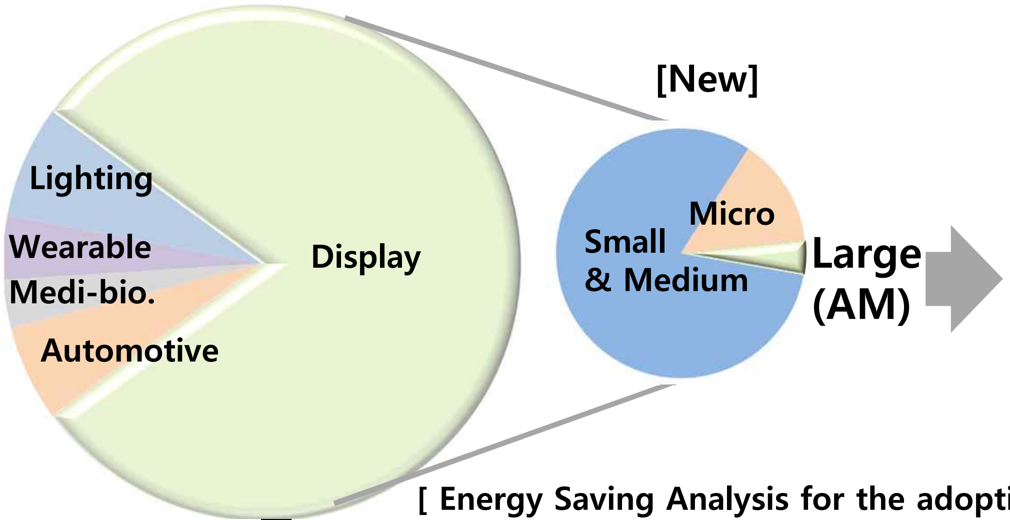
02 국내외 시장동향

초대형 디스플레이

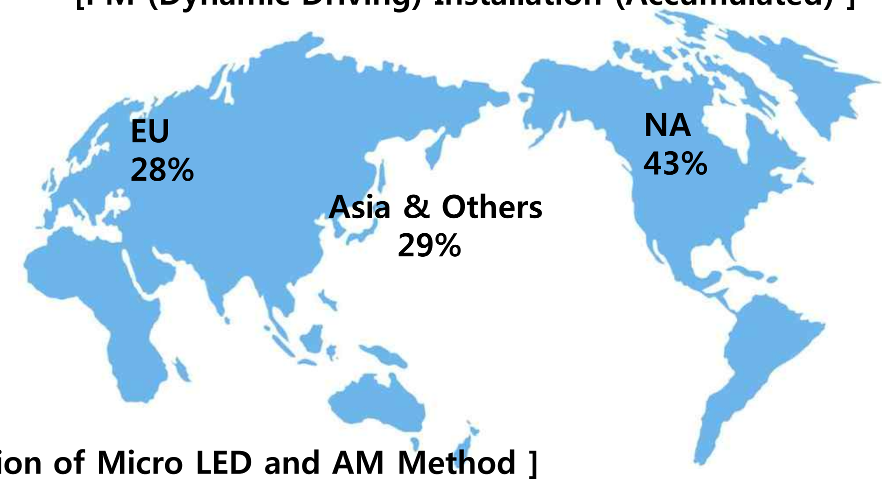
Industrial Potential of Large Display in the field of Micro LED Application

- New Market : Cinema, Conference, Education, Station, Hospital, Monitoring Room etc.
- Conventional passive matrix LED display : Too much power consumption

→ New Driving AM Method associated Micro LED (Paris Agreement of Climate)



[PM (Dynamic Driving) Installation (Accumulated)]



[Energy Saving Analysis for the adoption of Micro LED and AM Method]

구 분	Save (%)	PWR (GWh)	Saved PWR (GWh)
Ultra Public Display	50	4,837	2,419
Automotive (Including Autonomous)	20	300	171.1
Mobile*	75	91.7	68.8
AR/VR*	75	91	68.2

02 국내외 시장동향

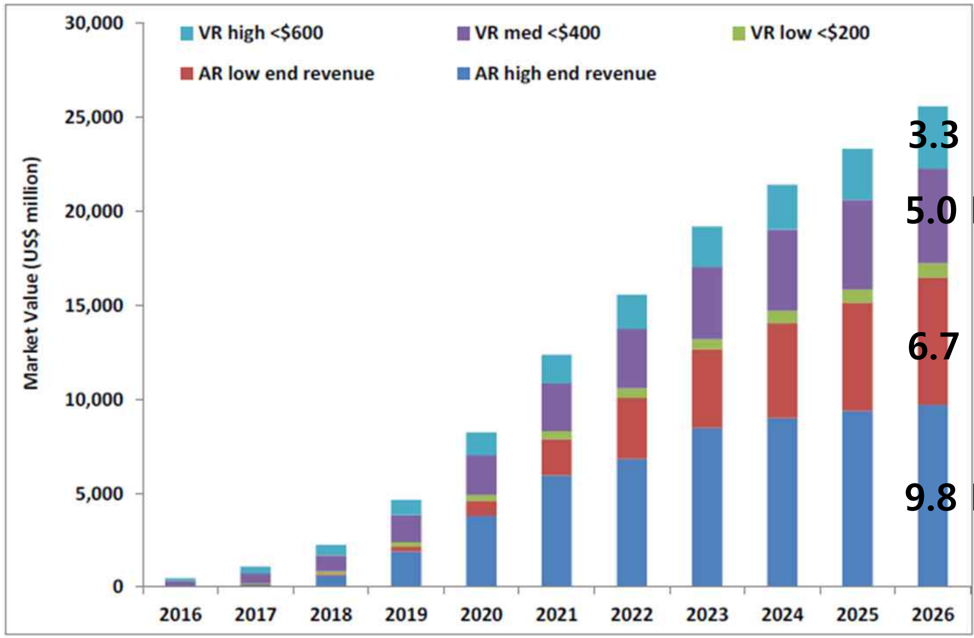
AR/MR/VR Market

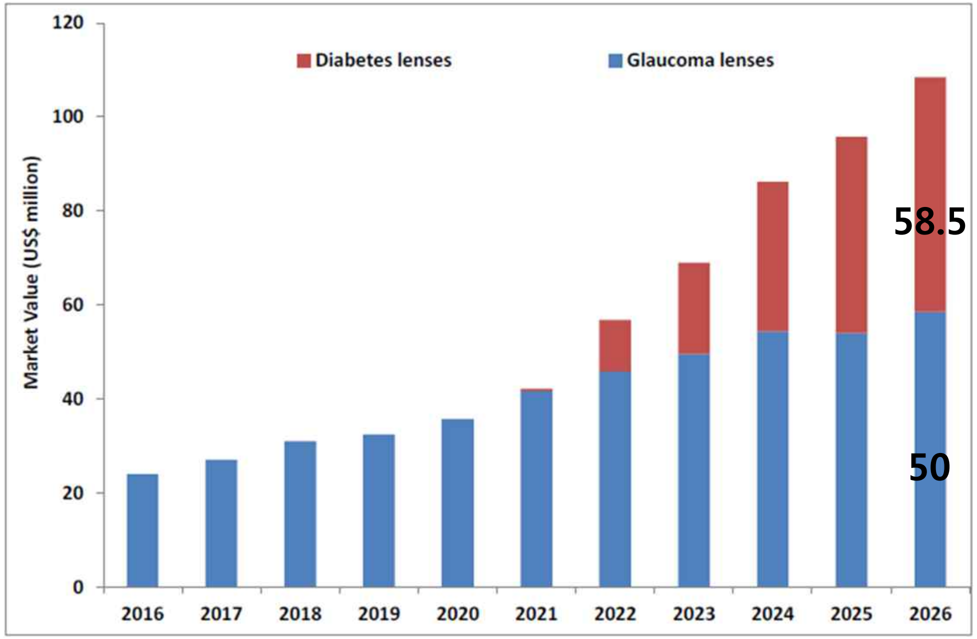
- '26년 AR/VR 기기 시장 165 억불 / 90억불 전망 (Near-eye, On-eye Devices)
- High AR (MR) 98억불로서 시장점유율이 가장 높을 것으로 예측
- 웨어러블 의료/바이오 : Diabetes (당뇨병), Glaucoma (녹내장) 모니터링

Google (Soli), Microsoft (interaction software), Vuzix and Ahteer Labs (eye-worn computers)

Challenges for Commercialization : gesture recognition, eye-tracking

1. Power Supply (Form factor)
2. Flexiblility (Design-ability)
3. Miniaturization (Integration)
4. Encapsulation (Anti-Moisture)

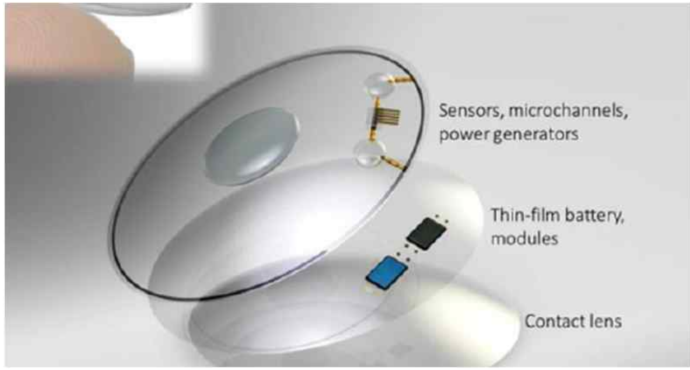




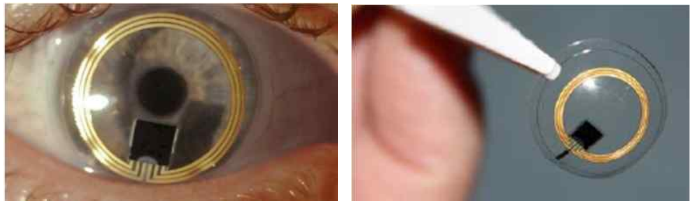
02 국내외 시장동향

On-Eye Wearable

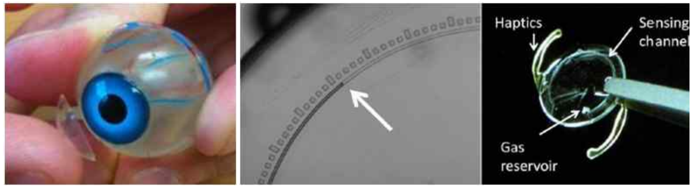
KIST → Diabetes Monitoring



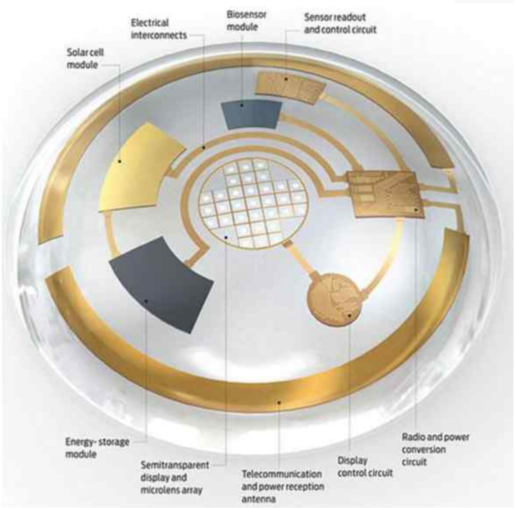
Sensimed AG → Glaucoma Monitoring



University of Michigan-Stanford Univ. & Bar Ilan Univ.–Auburn Univ.



Google → Glucose Monitoring

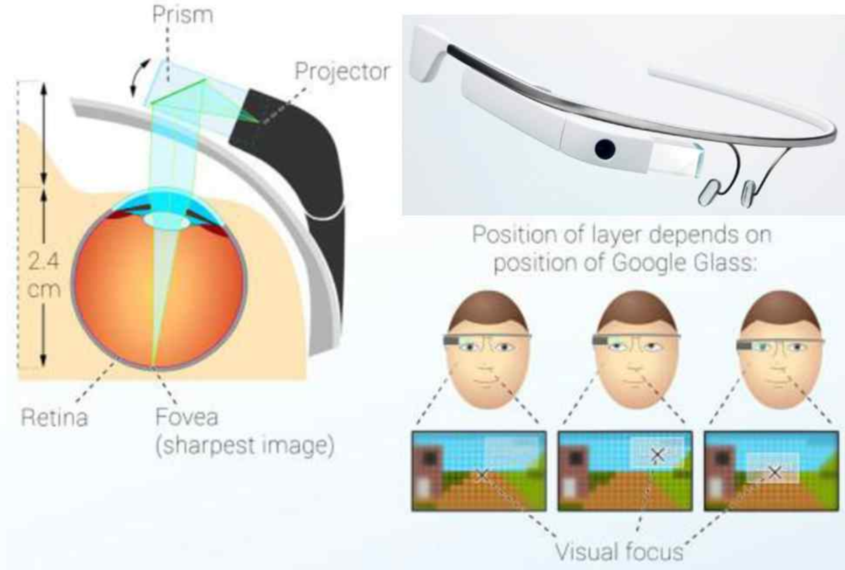


Antenna, Power-conversion, µLED, Energy-storage, Biosensor

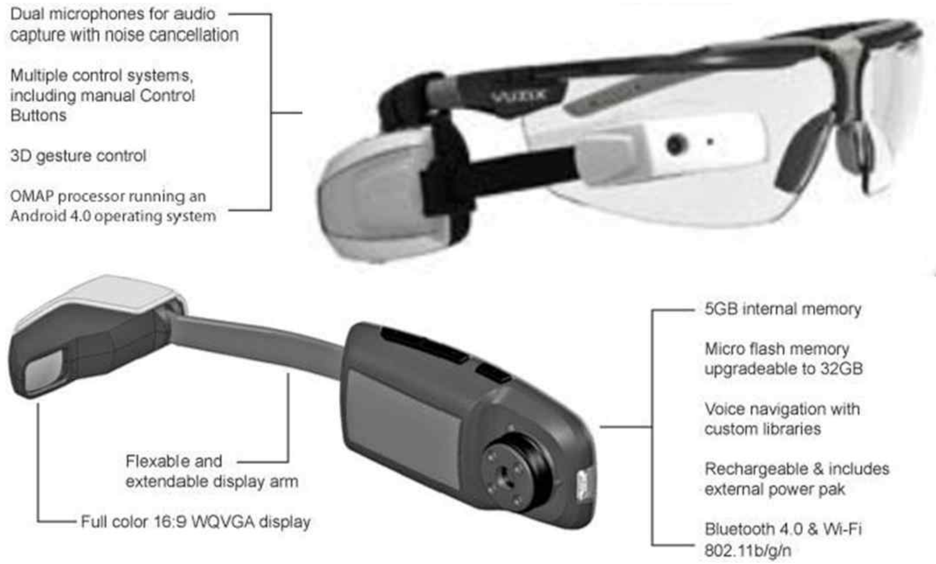
02 국내외 시장동향

Near-Eye Wearable (AR)

Google Glass

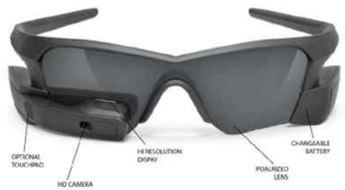


Vuzix M100



Epson BT-200

RECON JET



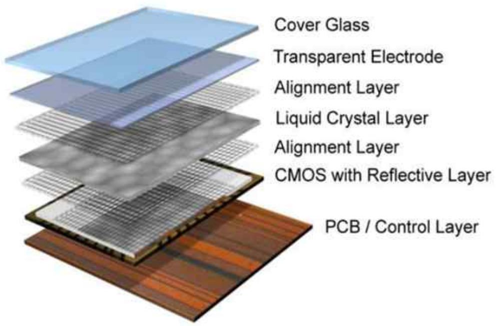
Optivent

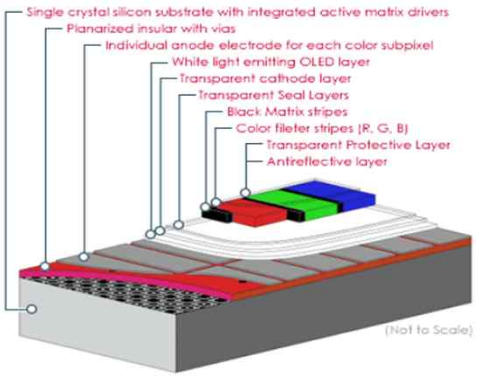
Hololens

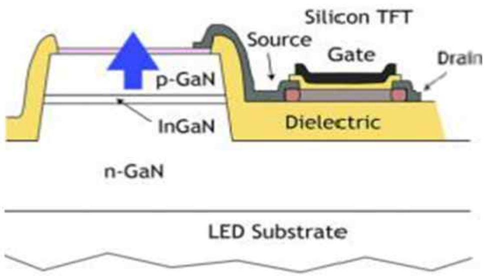
Smart Eye Glass

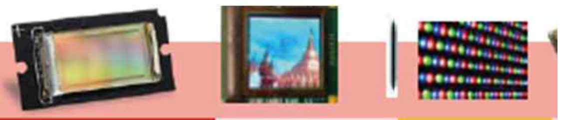
02 국내외 시장동향

Near-Eye Wearable









Key factors	LCoS	OLEDoS	MicroLED	
Resolution (PPI)	> 6,000	~ 3,000	15~300	2,000 → 10K
Power consumption	1x	4.7x	0.5x	
Cost	100%	1000~200%	Too High	
Complete Chipset Readiness	◎	△	X	
Virtual Screen Size (FoV)	~ 90	~ 70	X	
Display Size (Eyewear Set Size)	0.2" ~ 1.2" (1x)	0.5" ~ 1" (1x)	2" ~ 1000" (NA)	< 1 "
Brightness (light source, nit)	30,000	~500	30,000	> 50K
Contrast Ratio	>500	>1,000	>1,000	> 3K
Screen Door Effect (fill factor %)	> 91	< 30	<< 30	
Optic Compensation	◎	X	X	OK
Technology/Product Readyness	Matured	Emerging	Early	

Source : 2017 LED융합산업허브구축사업, 라온테크 김보은 대표, IDTECH 2017, Yole Development 2017

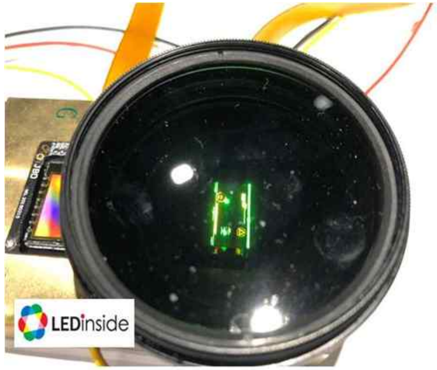
02 국내외 시장동향

Near-Eye Wearable SID 2019

[Plessey Semi._UK]

- AR application
- 0.7″ with 8um blue LED chips on JDC CMOS backplane
- 1920 x 1080 resolution

[Jade Bird Display_UK]

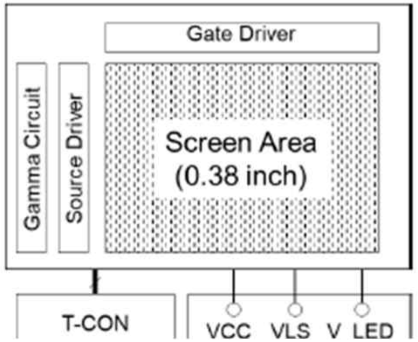


- 600 dpi bi-color(R/G) uLED with transferring technology.
- Mono-color : 5000x4000 with a million nits.
- Minimum pitch : 2.5um (mono-chrome)
- 5,000 PPI Try

02 국내외 시장동향

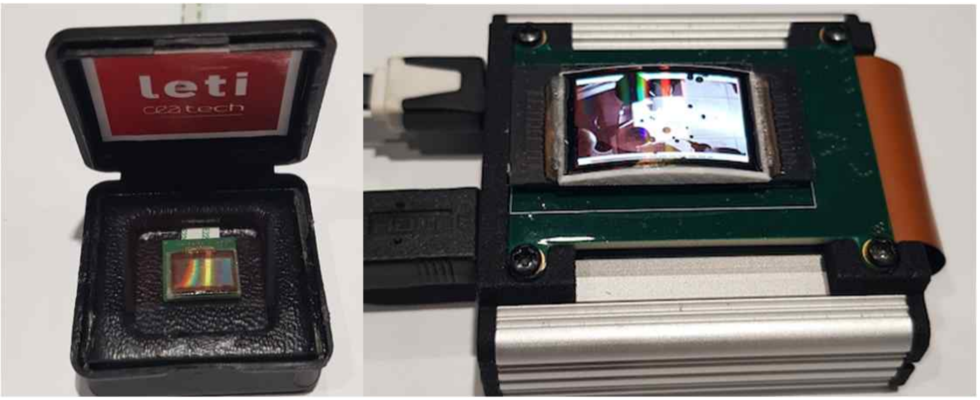
Near-Eye Wearable SID 2019

[Sharp (Japan)]



- AR application
- 0.38” , 1,053 PPI
- 209,088 sub pixel
- 1,000 nits

[LETI]



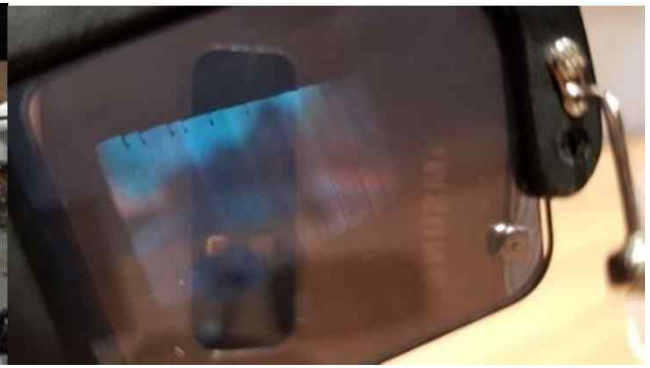
- 2,000 PPI, Mono-/Full-Color
- Hybridization
- 100K nits
- If AR optics efficiency is 10%, brightness of see-through type display will be over 10K nits

Near-Eye Wearable SID 2019

[eMargin]

- Micro-OLED
- 1920 x 1080 FHD
- 0.66-inch
- 2,000 nit
- 3,500 PPI

[BOE]



- 0.39” - 1920 x 1080 FHD
- 500 nit
- 5,644 PPI

02 국내외 시장동향

Players

Apple	**Smart Watch** 개발완료, 양산? LTPO 기술전환	Mikro Mesa	**TVs** 50 인치이상, 50 PPI 이하	Sony	**TVs** 20 PPI
				VueReal	**AR/VR,** 6,000 PPI
AU Optronics	**Automotive** 12.1 인치 Full-Color 디스플레이	Rohinni	**R2R 전사** 조명, 자동차	PRP Optoelectronics	**AR/VR,** **Pico Projector**
eLux	**Fluidic 전사** Foxconn 인수	PlayNitride	**Stamp 전사** 1,500 PPI	Plessey Semiconductor	**AR/VR,** **Pico Projector**
JBD	**AR/VR** 5,000 PPI 개발 중 10,000 PPI 계획	Lumiode	**AR/VR** N type TFT 적용 GaN Tr. 개발	Oculus	**AR/VR** OLED 헤드셋 InfiniLED 인수

02 국내외 시장동향

Players

SAMSUNG ELECTRONICS	**TVs, DID** 30 PPI, 146”, 75” The Wall
Visionox	초대형 디스플레이 `17년 개발착수
Seoul Semiconductor SEOUL SEMICONDUCTOR	uLED 광원 개발 진행 (`16~)
LG Display	**TVs, PID** IFA 2018 초대형 디스플레이 출시
Nichia	LED 광원 선도기업
San'an Optoelectronics 三安光电 Sanan Optoelectronics	세계 최대 칩제조 100 um 크기 양산
Lumens LUMENS Leading the LED Revolution	**TVs, AR** 139” 디스플레이 2600 PPI 단색
Micro Nitride	Nitride Semi. 자회사, UV uLED 개발
Lextar	**RGB LED** AUO 자회사
Aledia	**GaN on Si** 3D GaN LED
Glo	GaN 나노와이어 uLED 개발
HC Semitek 华灿光电股份有限公司 HC SemiTek Corporation	**RGB LED** 100 um 크기 양산
Changelight 乾照	대형 디스플레이 옥외/옥내용
Epistar EPISTAR	**RGB LED** 100 um 크기 양산
Epileds Technologies EPILEDS Light tech. Green future	**RGB LED** Foxconn 지분투자

02 국내외 시장동향

Roadmap

Screen Display

↓

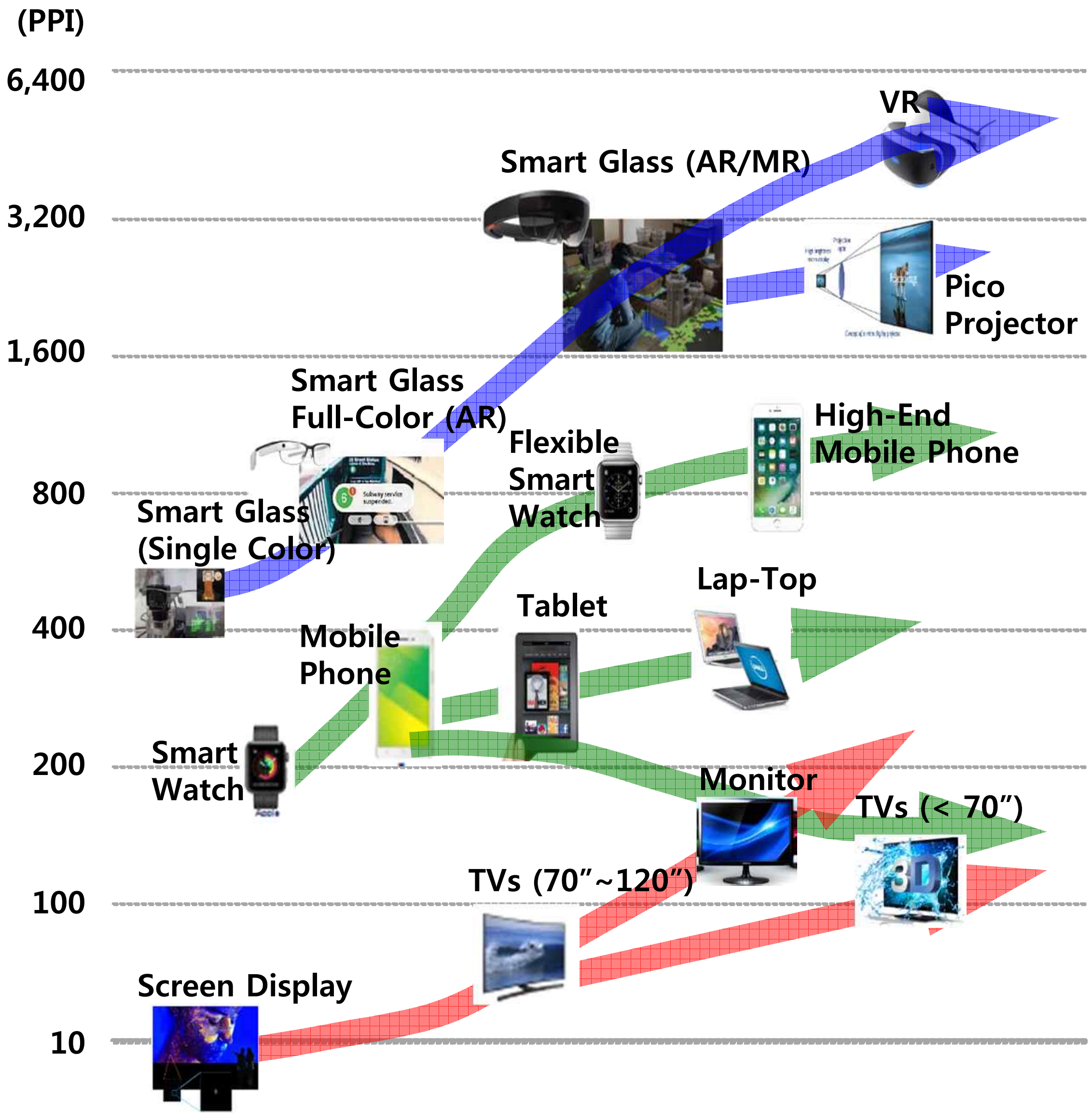
Smart Watch

↓

Augmented Reality (Low Density)

↓

Mixed Reality (High Density)



Quality-Cost Factor

< Manufacturing Process >

Epi.

Sapphire (LLO), Silicone (CLO) template for separation method

Panel & Module (Integrated Process)

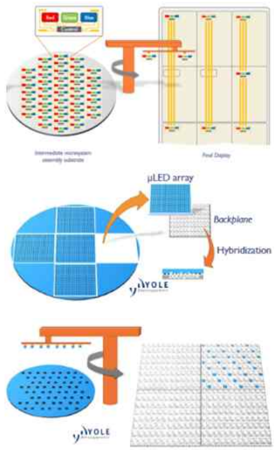
Front-end

Back-end

Chip Process for PTP&B

Applications

- Display
- AR/VR
- Wearable
- Vehicle
- Lighting



Wafer Size → Cost Reduction, Production Capability, Efficiency

Product Type → Epitaxial Quality, Chip Structure, PTP&B Method, Repair

* PTP&B : Pick-Transfer-Place&Bonding

Selective PTP&B, Wafer Bonding, Monolithic Integration

Defect Inspection & Repair

Backplane(AM/PM Driving) → LTPS, Oxide-TFT,CMOS, GaN, PCB

Panel Driver

03 기술동향

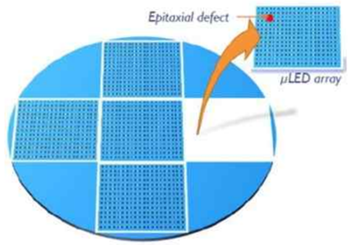
Wafer / Epi. Quality-Cost Factor

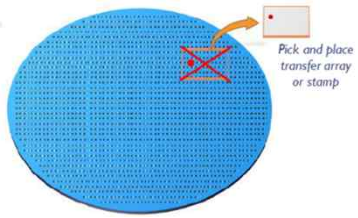
Area Wafer Bonding Monolithic Integration	Selective Transfer Pick&Place Bonding
⬆	⬆
AR/MR, HMD, HUD, Smartwatches,	TVs, Smartphone, Large Display

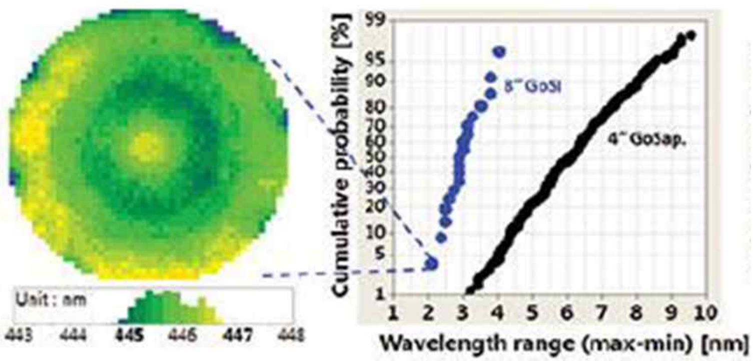
➡

Quality Control
→ Single Chamber System

Epi. Level Inspection System
→ EL Detection Layer Formation

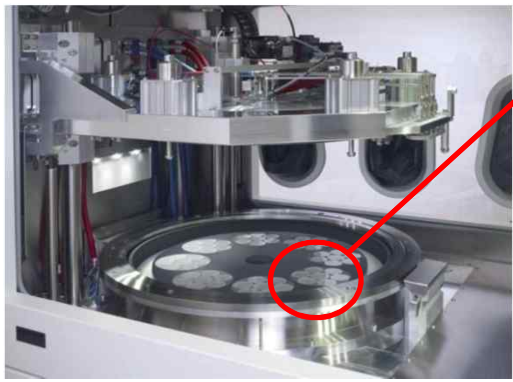


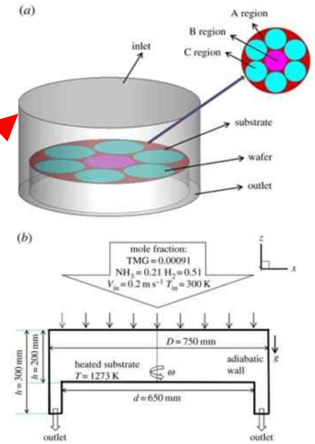




⬅

[Multi-Chamber System]

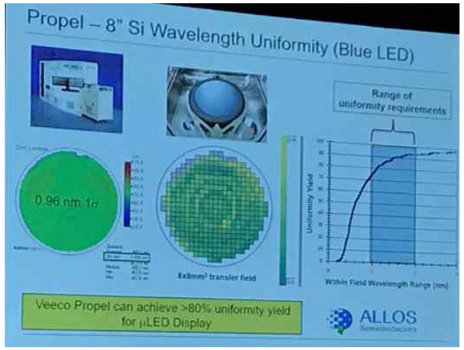




Wafer / Epi. Quality-Cost Factor

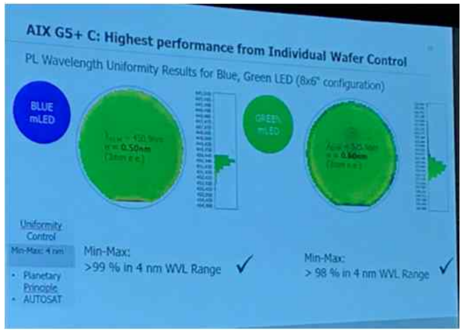
SID 2018

MOCVD : Veeco



- 6"/8" Wafer (4nm)
- Blue/Red
  : 80% / 95%
- Defect (0.8 ㎛) : 95%

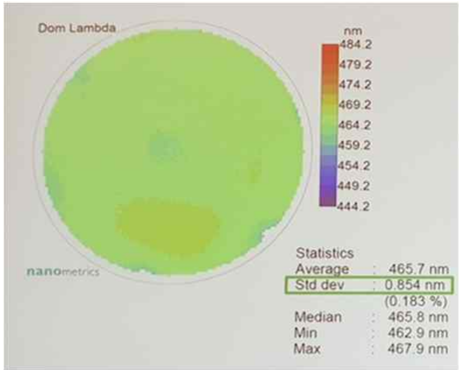
MOCVD : Axitron



- 6" Wafer (4nm)
- Blue / Green / Red
  : 99% / 98% / 99%
- Cassette to Cassette
  automation

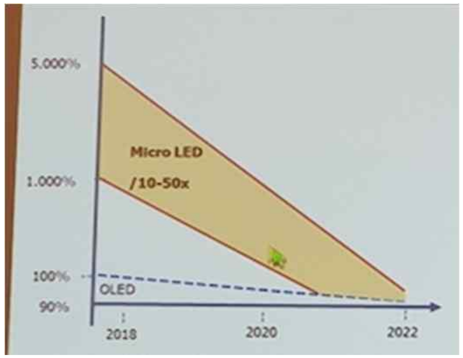
SID 2019

Epi. : ALLOS



- 8" Wafer (2.5 nm)
- GaN on Si

Cost : Axitron



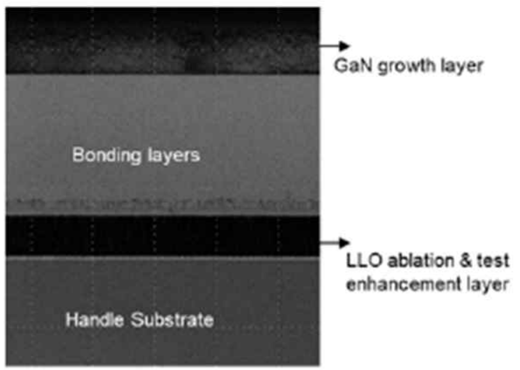
- 50X than OLED
- < 150$ -4K, 75"

03 기술동향

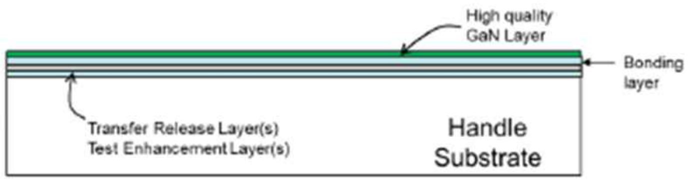
Epi. Template

Epi. Template for EL Test & Easy Transfer (QMAT)

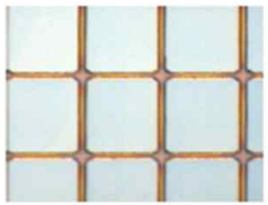
- **Multi-layers structure with an functional layer for testability and mass-transferability**
  - QMAT high quality GaN and GaAs templates can have pre-patterns to define less than 5μm LED die size with street widths of about 1μm.
  - **Reduction of Sidewall Effect → this ultra-fine patterning enhances stress control for epi growth and will result in better LED performance**

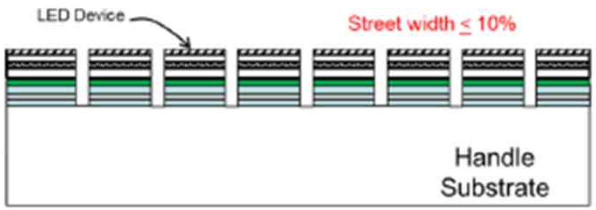


TEM cross-section

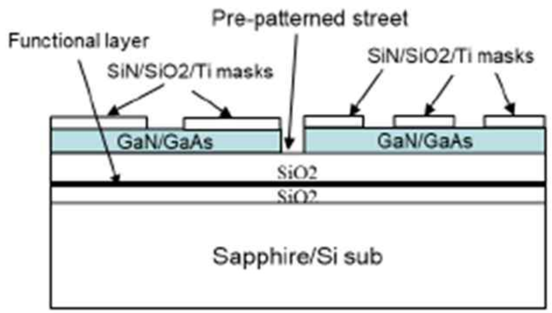


P-GaN, MQW Pre-Patterning → Epi. Layer Transfer → Reverse side of N-GaN Patterning





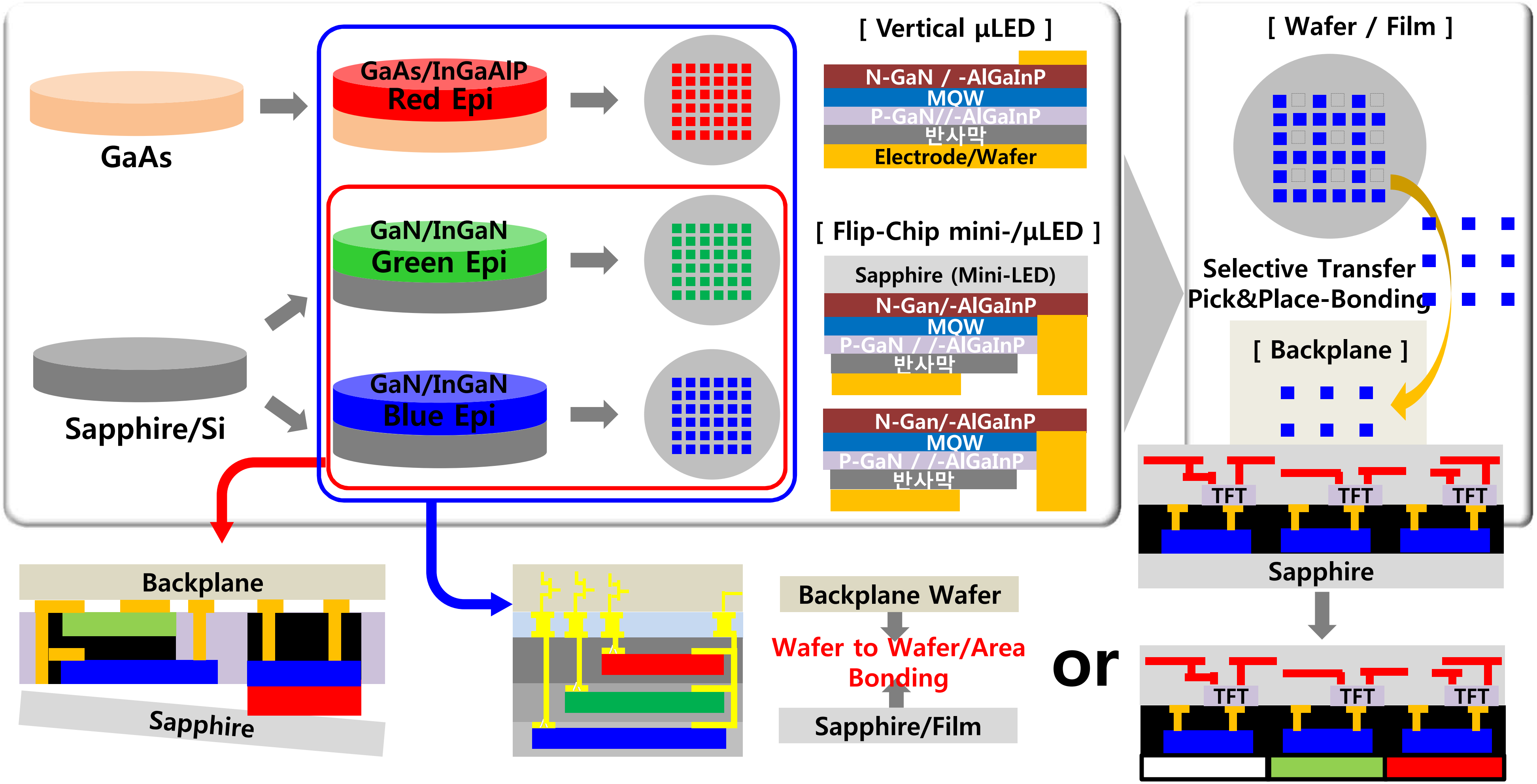
High quality GaN template hexagonal nanowire color emission → Side wall heat (This layer is sandwiched between heat and energy isolation Layers) → Reduction of thermal damage by LLO → Save manufacturing cost and have all advantage for testability and mass-transfer. .



Reference : Dong Lee, et. al., "Ultra-Fine High Efficiency MicroLEDs with Testability and Transferability Using Layer-Transfer Technology" SID 2019, QMAT, Inc. Santa Clara, CA, Stanford University, Stanford, CA

03 기술동향

Pixelization

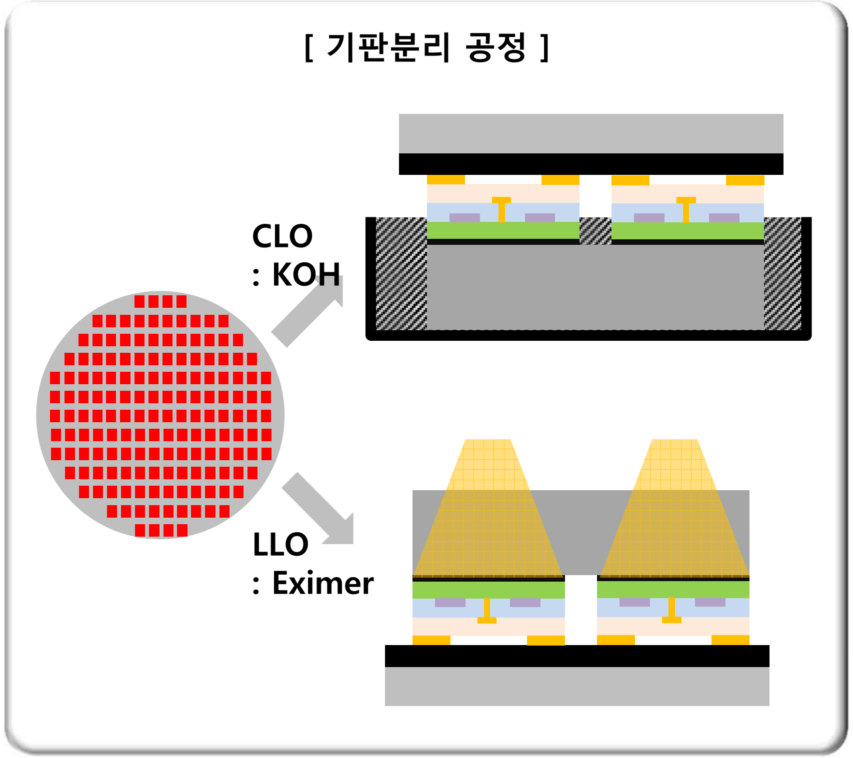


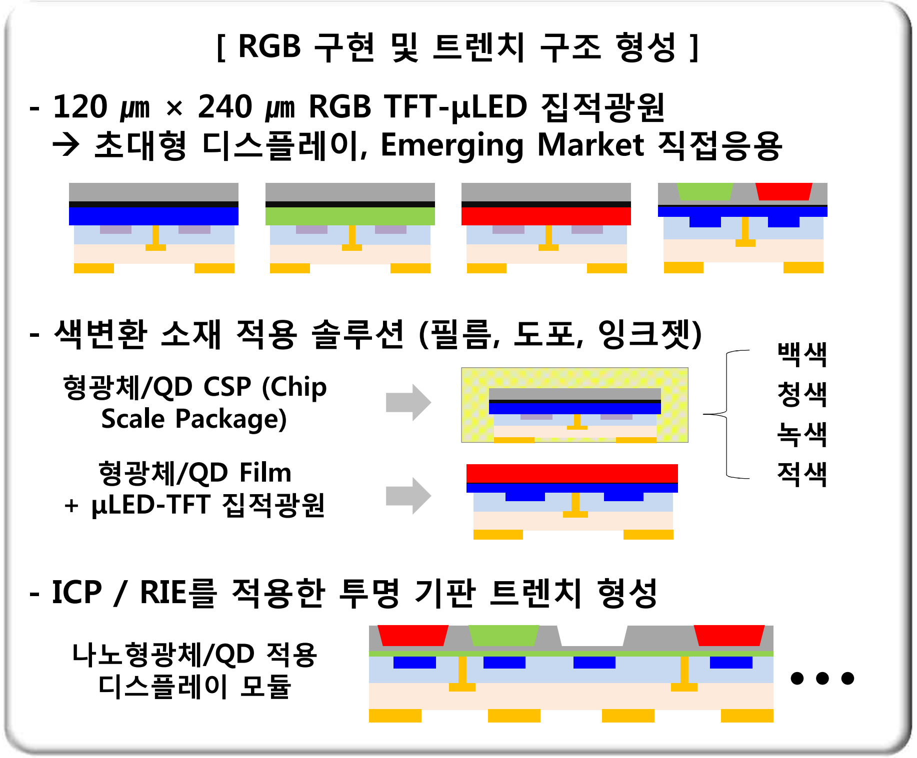
Pixelization

Associated with LLO/CLO Process

Trench Structure in sapphire substrate

- QD & Nano-Phosphor can be printed or dotted on Blue & Green Micro LEDs based on GaN
- Opaque Si or GaAs epi. substrate should be removed, and then attached film or sapphire substrate on the red epi. layer with color conversion materials.



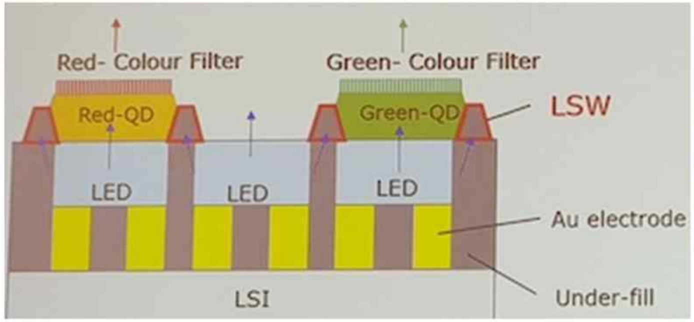


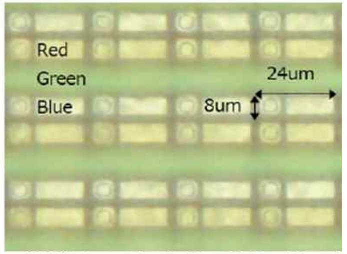
03 기술동향

Pixelization

1,053 PPI, 0.38 inch MicroLED+QD

- **MicroLED display bonded onto silicon driver → Near-eye Display (AR/VR, HMD)**
  - QD materials were mixed into photo-resist to be used for photolithographic patterning process.
  - Inkjet Process : In dispersants, the additives, photoinitiator and curable resin are mixed together to activate photosensitive performance.





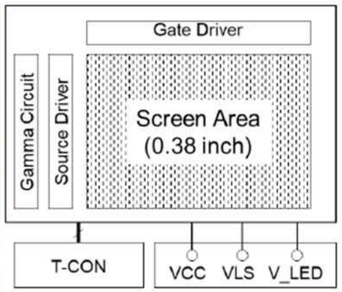


Table 2. Specification of Silicon Display

Item		Specification
Screen size		0.38 inch
Pixel density		1,053 ppi
Resolution (number of dots)		209,088 sub-pixels (H:352 x RGB x V:198)
Pixel size		24 x 24 um^2
Brightness*		1,000nits
Color coordination (x,y) in CIE1931	Red	(0.620, 0.308)
	Green	(0.208, 0.645)
	Blue	(0.146, 0.040)
Color gamut (x,y)	v.s. BT2020	63.7%
	v.s. NTSC	85.3%
	v.s. sRGB	120.5%

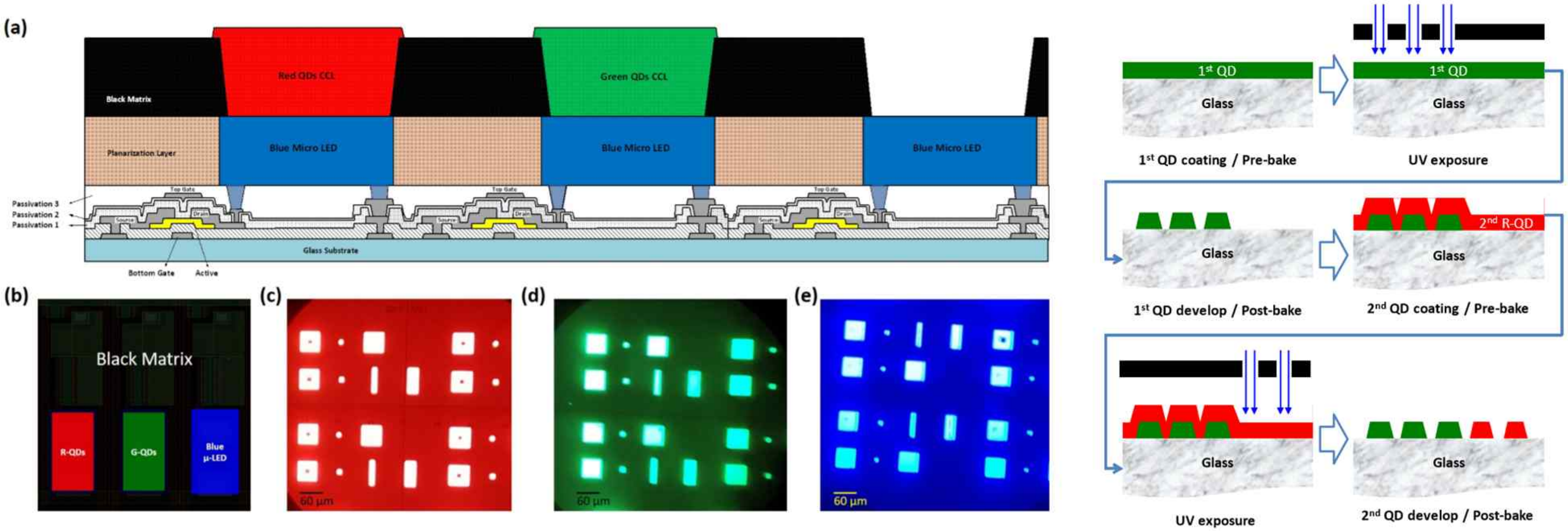
*Driving condition: 165mA, 60 frame/sec and fully lit up conditions.

Reference : Hiroaki Onuma, et. al., "1,053 ppi Full-Color "Silicon Display" based on Micro-LED Technology" SID 2019, Sharp Corporation

Pixelization

10 um MicroLED + G/R QDs (ADRC Kyung Hee Univ.)

- **Negative QD photo-resistor for fine pattern QD CCLs.**
  - ➢ PGMEA is used as main solvent in photo-resistor
  - ➢ In dispersants, the additives, photoinitiator and curable resin are mixed together to activate photosensitive performance.
  - ➢ The QDs CCLs could be patterned down to 10 μm pixel size successfully

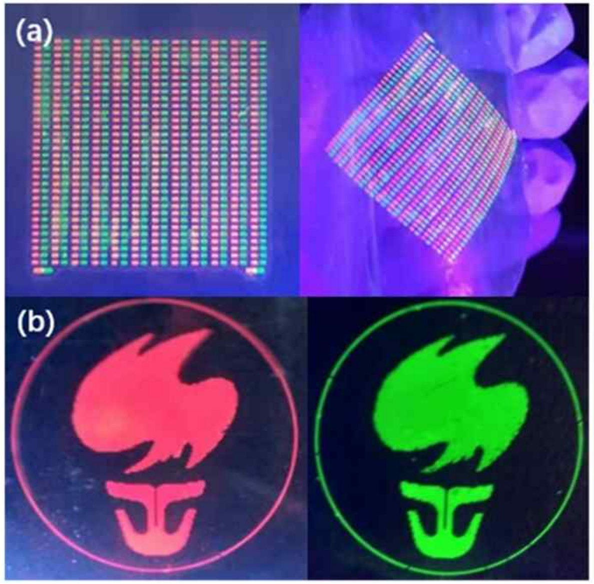


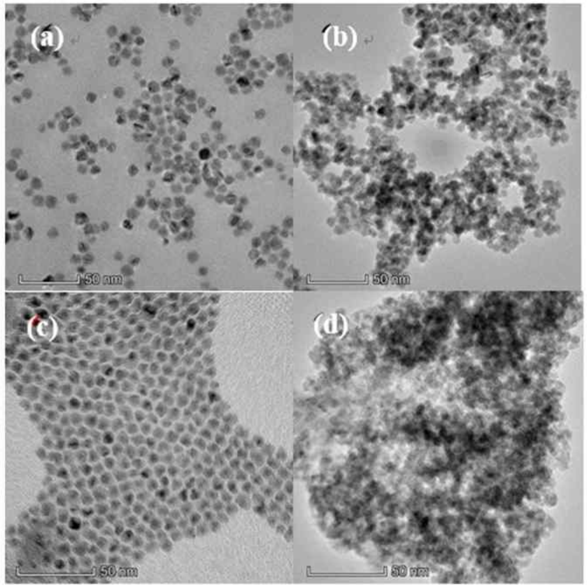
Reference : H.M Kim, et. al., "10 μm Pixel, Quantum-dots Color Conversion Layer for High Resolution and Full Color Active Matrix Micro-LED Display" SID 2019, ADRC Kyung Hee Univ., TAKOMA Co.,Ltd, HunetPlus Co.,Ltd, ZEUS Co., Ltd, KOPTI

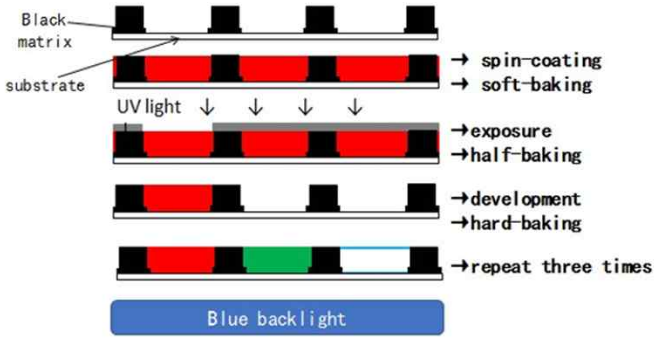
03 기술동향

Pixelization

- **Modified QD (Southern University of Science and Technology in China)**
  - **Higher quantum yield up to 60%-70%, and a high optical density over 1.5. Author**
    - Solving the problems of QD's solubility in photoresist and its adhesion to the substrate of PET
    - The original QDs with emission peaks of 625 nm (FWHM=30 nm, QY=88 %) and 520 nm (FWHM=50 nm, QY=81 %), respectively, while the peaks change to 629 nm (FWHM=30 nm, QY=78 %) and 527 nm (FWHM=44 nm, QY=64 %) after modification, respectively.







Average size of obtained QDs (a) 8.9 nm, red QDs; (b) 112 nm, modified red QDs; (c) 8.0 nm, green QDs and (d) 105 nm, modified green QDs

Reference : X. Bai, et. al., "Flexible Quantum Dot Color Converter Film for Micro-LED Applications " SID 2019", Southern University of Science and Technology, Shenzhen Planck Innovation Technologies Co. Ltd., Department of Chemistry.

03 기술동향

Assembly Technologies

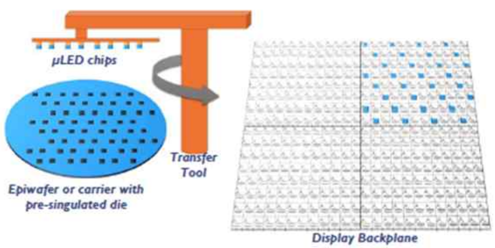
20	80	300	500	1000	3000	5000

Video Display | 4K 55" TV | Smart Watch | Smart Phone | AR/MR/VR /HUD

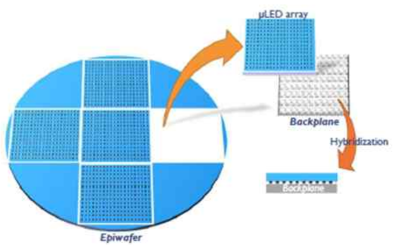
Size & Bonding Method

- μPKG/COB
- Massively Selective Transfer Pick&Place
- Monolithic Integration, Wafer Bonding

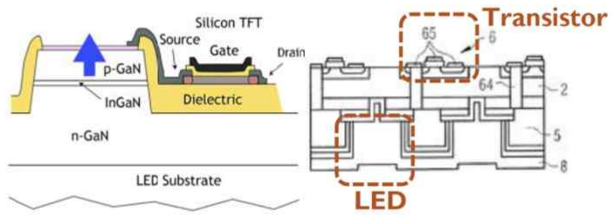
[Selective Transfer Printing]



[Wafer Bonding]

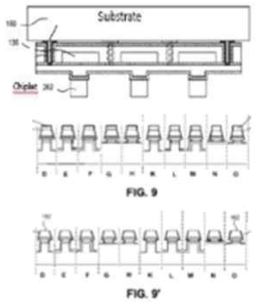
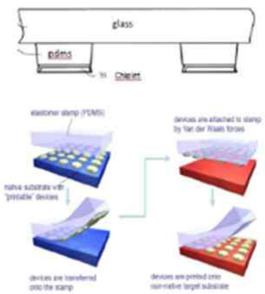
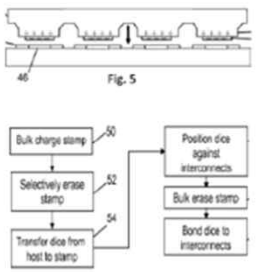
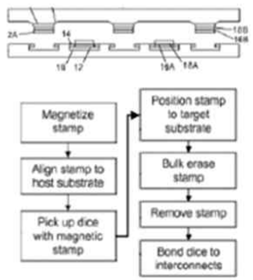
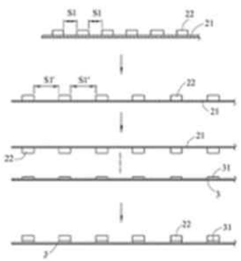
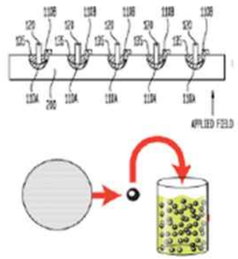


[Monolithic Integration]



Source : Yole Development 2017 Micro LED Displays

Assembly Technologies

	Electrostatic MEMS	Elastomer Stamp	Electrostatic Stamp	Magnetic/Electromagnetic	Adhesive	Fludic Assembly
Company	LuxVue-Apple	UIUC, X-celeprint, Semprius, Cooledge, AUO, CSOT, ITRI	Cooledge, AUO	PlayNitride, ITRI, Cooledge	Playnitride, Intel	Nth degree, Sharp, PSI
Principle (Patent)						
Core Tech.	Electrostatic pick up head	Van Der Walls force, PDMS	Transfer stamp, Electrostatic charge	Magnetic coating on chip	Stretchable ahesive film	uLED in a suspension, aligned with a EM field

03 기술동향

Assembly Technologies

Players

1. Pick-and-place transfer (Samsung, Sony)
2. Electrostatic MEMS (Apple/Luxvue)
3. Electrostatic stamp (Cooledge, AUO, Vuereal)
4. Elastomer stamp or roll (X-Celeprint, ITRI, KIMM)
5. Ultrasonic/acoustic roll (Innovasonic)
6. Magnetic/electromagnetic stamp (ITRI)
7. Adhesive stamp (Playnitride, Intel)
8. Mechanical transfer (Rohinni)
9. Thermo-mechanical laser transfer (Uniqarta, QMAT, KOPTI, Hansol)
10. Laser ablation transfer (Optivate, KOPTI, Hansol)
11. Fluidic self-assembly (Nth degree, Sharp, PSI)

Challenges

1. Efficient pick up→ selecting chips
   → placement for various different pixel density
2. Ultra-high transfer yield requirements : 99.9999999%(no dead pixel)
3. Throughputs requirements are Millions dies/s
4. Very high precision of placement (within 1 μm)
5. Effective (in-situ) inspection/testing methods
6. Smart rework, sufficient redundancy scheme

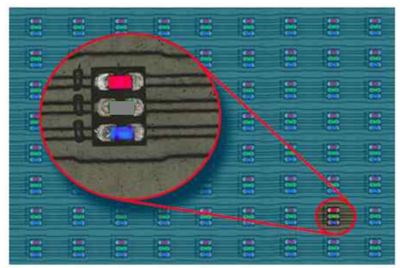
Feature/ Technology	MEMS	Mechanical (pin)	Elastomeric stamp	Laser-assisted	Ultrasonic-assisted	Fluidic self-assembly
Reliability	Moderate	High	Moderate	High	High	Low
Throughput	High	Low	Moderate	High	High	High
Scalability	Low	Low	High	High	High	High
Selectivity	High	High	Low	High	High	Moderate
Success probability	Low	Moderate*	Moderate	High	High	Low

Test & Repair

Defect & Transfer Yield

- **Missaligned, Not melt solder/bump for electrical connection**
  - ➢ FHD 99.9% Yield → defect 6,221 ea
  - ➢ UHD 99.9% Yield → defect 24,883 ea
- **Chip removal → Residue solder removal → Solder paste by transfer pin → chip placing → curing by air heat**
  - ➢ 1min. of Repair time → FHD 0.1% fail(4.32 days), UHD 0.1% fail(17.28 days)

+



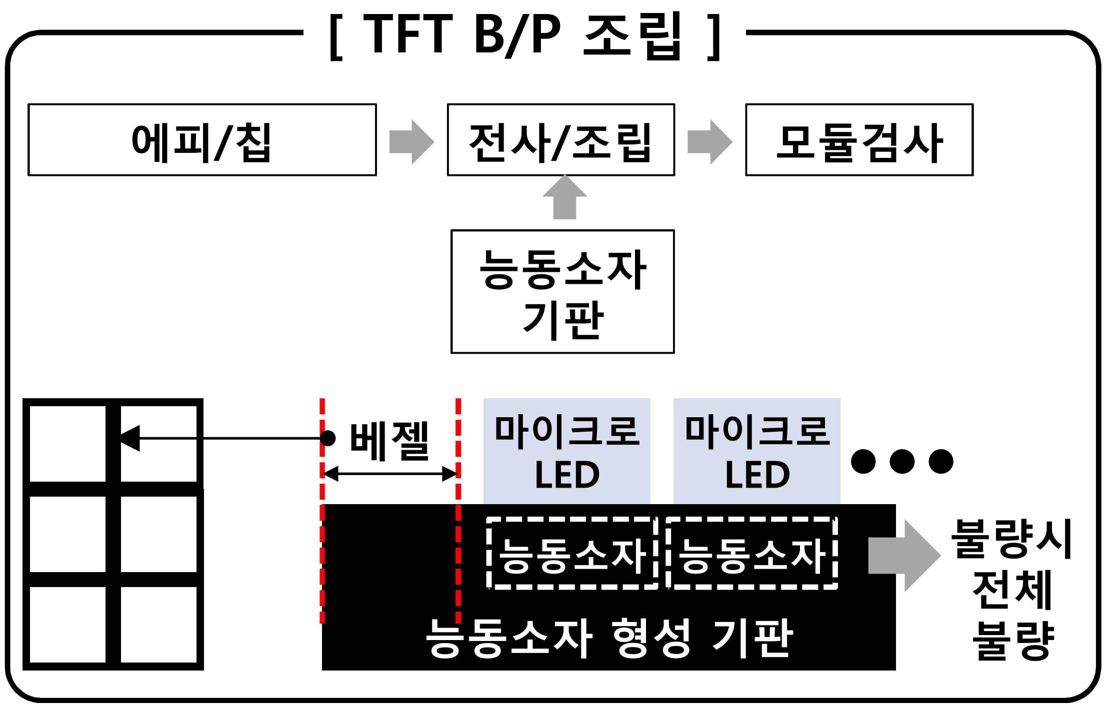
Wafer Re-array Transfer Substrate Repair/Rework

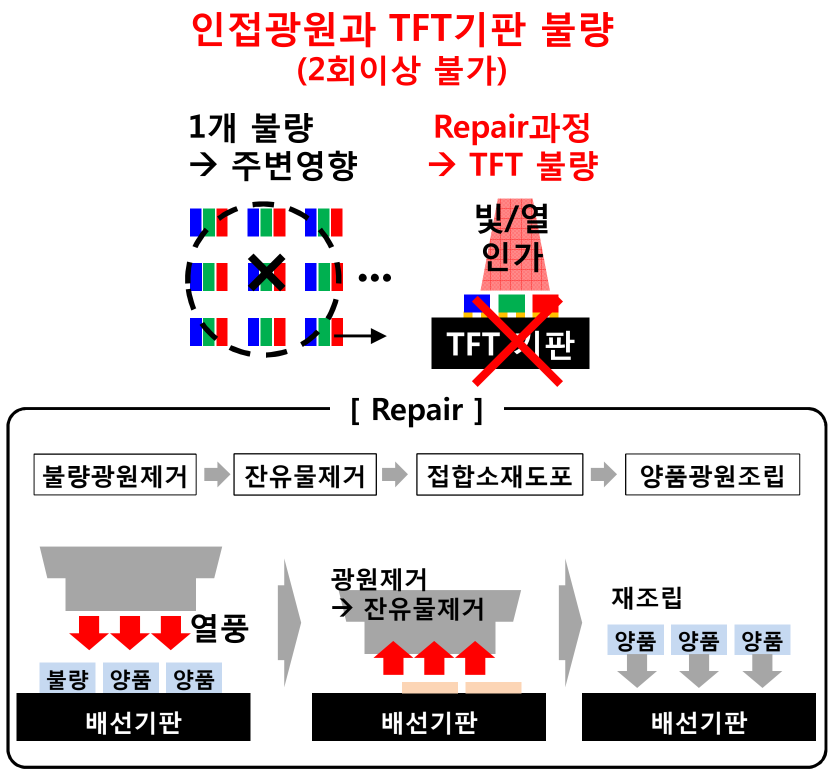
03 기술동향

Test & Repair

Before Transfer Printing, Using Good Die Information

- The uncertainty of PL inspection result in the increase of production cost → EL Inspection
- The failure may occur on repair process because of removing of small pixel size, rearrange of good die etc.
- The extraction method of well-known good die information can be helpful used in associated with transfer process

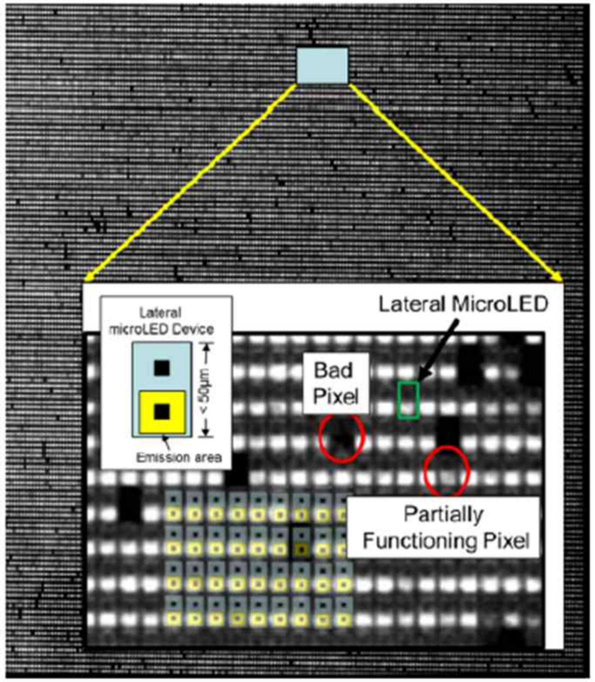


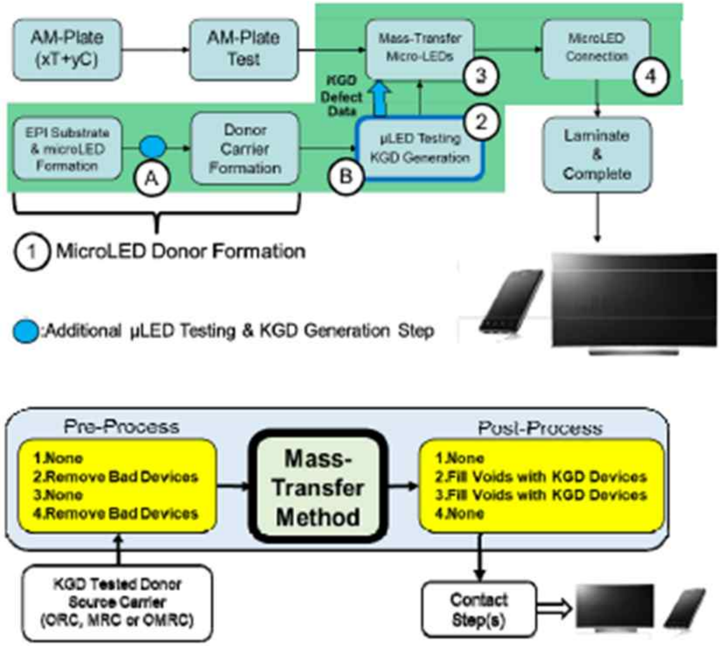


03 기술동향

Test & Repair

- **Integration of in-process EL functional test into the mass-transfer assembly process flow (Remove Bad Dies → Only Known Good Die Transfer → Repair)**
  - The test concept is to drive each microLED device in a massively parallel fashion without direct electrical contact to measure the light generation capability of each microLED
  - EL test response of over 55,000 lateral microLEDs measured in less than 5 seconds resulting from the injection and measurement of a lateral microLED device array on an EPI growth substrate





For parallel contact with EL Method

⬇

Should support the structure of MicroLEDs Epi. and Chip

⬇

Commonization of anode or cathode ??

Reference : Francois J. Henley, "Evaluating In-Process Test Compatibility of Proposed Mass-Transfer Technologies to Achieve Efficient, High-Yield MicroLED Mass-Production, Tesoro Scientific, Inc., Saratoga CA

Test & Repair

- **Integration of in-process EL functional test into the mass-transfer assembly process flow (Remove Bad Dies → Only Known Good Die Transfer → Repair)**

	Mass-Transfer Technology	Companies	MicroLED Selectability	Donor Carrier Type	Required Pre-Process	Required Post-Process	Throughput	Mass-Transfer Process Flow	MicroLED KGD-Driven Production Compatibility
1	Single Pick & Place (Active)	Ex. Hoson GS100BH	Yes	MRC	None	None	Very Low (<0.1M/Hr)	1	Compatible Software Selectable Display Array Setup
2	Array Pick & Place Stamp (Passive)	Xceleprint, Apple & Others	No (3-step)	OMRC	Remove Bad Devices or KGD Source Carrier	Requires KGD Fill Step or KGD Source Carrier	Low (~1-20M/Hr)	2	Less Adaptable (3-step)
3	Array Pick & Place Stamp (Active)	Apple (Luxvue)	Yes (2-pass)	MRC	None	KGD Fill Step (2nd pass)	Low (~1-20M/Hr)	3	Less Adaptable (2-step)
4	Roll-Roll (Passive)	KIMM	No (3-step)	OMRC	Remove Bad Devices or KGD Source Carrier	Requires KGD Fill Step or KGD Source Carrier	Medium-High (~10-50M/Hr)	2	Less Adaptable (3-step)
5	Self-Assembly (Passive)	eLux, SelfArray, NthDegree, PSI Co.	No (2-step)	ORC	Isolate KGD Devices	None	High (>50-100M/Hr)	4	Adaptable (KGD Pre-Binning)
6	Single-Beam Laser-Induced Forward Transfer (LIFT) (Active)	V-Technology Co., Ltd.	Yes (2-pass)	ORC	None	KGD Fill Step (2nd pass)	Potentially High (>50-100M/Hr?)	3	Adaptable (2-pass) Direct GaN Decomposition Unproven for Throughput/Yield
7	Array Laser-Induced Forward Transfer (Passive)	Coherent, Uniqarta	No (3-step)	ORC	Remove Bad Devices or KGD Source Carrier	Requires KGD Fill Step or KGD Source Carrier	Potentially High (>100M/Hr)	2	Less Adaptable (3-pass & Product-Specific Hardware Setup)
8	Single-Beam Laser-Assisted KGD "on-the-fly" Directed Assembly Architecture	Tesoro Scientific Inc. Smart-Assembly	Yes 1-pass possible (Active)	ORC	None	Reduce/Eliminate Device Fill Step	Very High (>200-500M/Hr)	1	Compatible Software Selectable Display Array Setup

Table I: Compatibility and Manufacturing Complexity Comparison of Various Mass-Transfer Approaches.

03 기술동향

Transparent MicroLED Displays

MicroLEDs on IGZO Oxide TFT Panel (CSOT)

- **Active matrix mini-LEDs full color display with high transmittance over 60%.**
  - Achieved over 114% NTSC color gamut with RGB flip chip mini-LEDs (100 um X 200 um)
  - The display has a high aperture ratio pixel of about 82%.
  - The area ratio of the mini LED chip is just about 6.5% in the pixel, RGB pixel size 0.55mm.

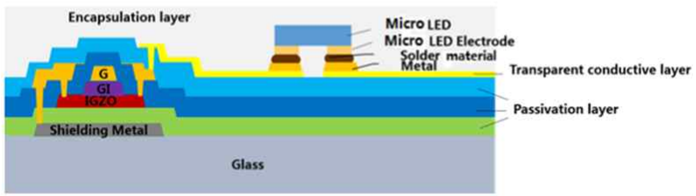
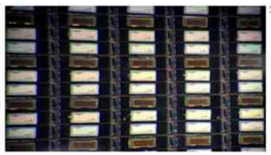


Figure 1: The Structure of the 8 inch transparent AM mini-LEDs panel

Table 1. 8 inch Transparent AM Mini-LED Display panel measuring Result			
	Wp/FWHM	X	y
R	628/15	0.6915	0.3079
G	525/27	0.1965	0.7458
B	470/17	0.1219	0.0804
NTSC(Area)	114.2%		
NTSC(Coverage)	99.7%		
Transmittance	60.4% (Base on YAG LED Backlight)		



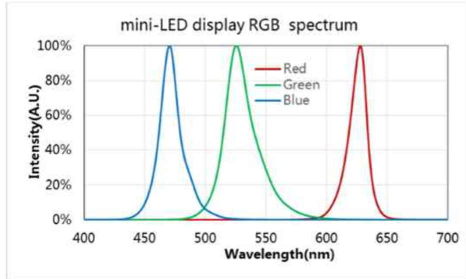
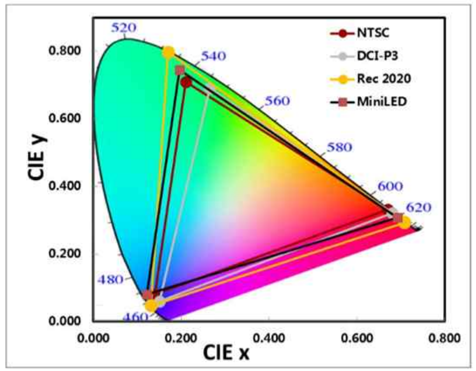


Figure4: The spectrum of RGB micro-LEDs



Reference : Jack Fan, et. al., "High transparent Active matrix Mini-LED Full Color Display with IGZO TFT Backplane" SID 2019, Shenzhen China Star Optoelectronics Semiconductor Display Technology Co., Ltd.. Shineon (Beijing)Technology Co., Ltd.

Transparent MicroLED Displays

[Playnitride : SID 2019]

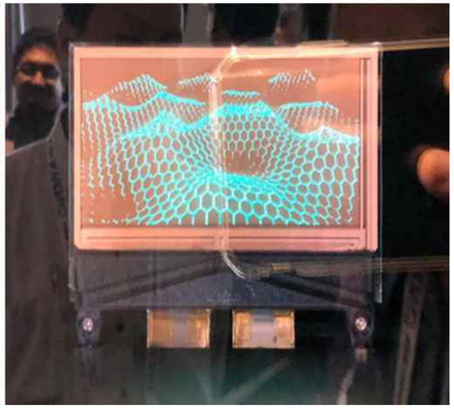
Active Matrix 7.56" LTPS, 60%
720 x 480, 114ppi, 600nits

Driving	Active Matrix
Panel Size	7.56"
Resoultion	720 x 480
Pixel Density	114 ppi
Brightness	> 600 nits
NTSC	116%
Transprancy	> 60%
Border Width	< 0.7 mm

[TIANMA : SID 2019]

7.56" full color transparent LTPS backplane

[X-display(X-Celeprint)]



5.1" 70PPI
Up to 30,000nit
developing

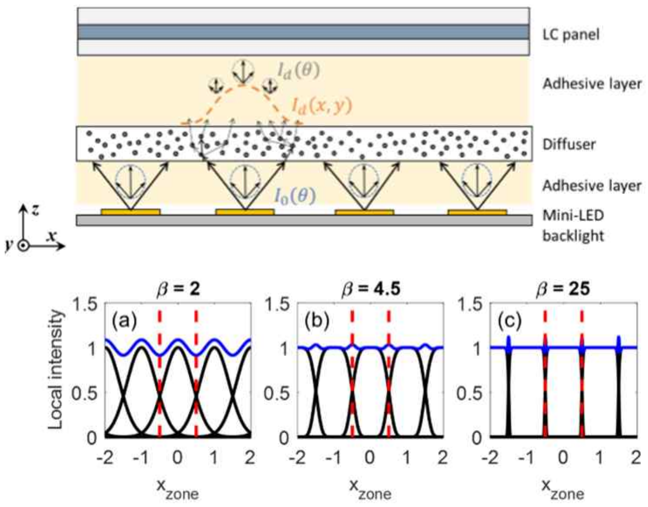
03 기술동향

Backlight Unit

High Quality LCD Display with White Mini-LEDs & MicroLEDs

- **Mini-LED Light Confinement, Optical Film, Local Dimming Technologies**
  - ➢ Halo effect (light leakage between adjacent black and bright pixels) can be suppressed to unnoticeable level by optimizing the LCD contrast ratio, number of local dimming zones, LED light expansion and local light confinement
  - ➢ Optical microstructure film, local dimming & RGBW algorithm mini LED optical field distribution and luminous efficiency should improve the performance of HDR display for smartphone

[Local Light Confinement]



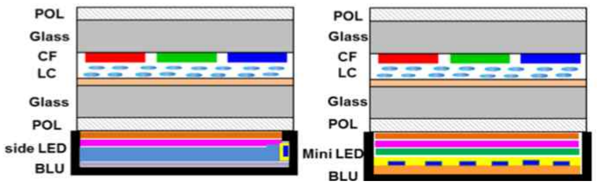
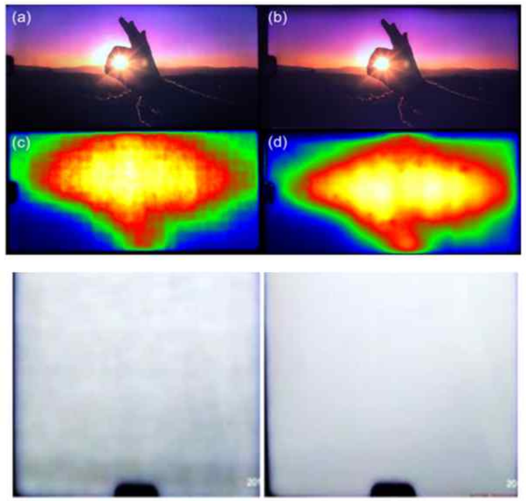


Table 2. Main parameters of normal IPS LCD and HDR LCD

Display	IPS normal LCD	HDR LCD
resolution	1080*2160	1080*2160
size	5.99	5.99
color gamut	86%DCI-P3	100% DCI-P3
peak luminance	500nits	>800nits
max contrast ratio	2000:1	>20,000:1
partition of local dimming	0	512
average power consumption	1W	1.4W

[288/512 Partitioning]



Reference : Yuge Huang, et. al., "Mini-LED Enhanced LCD for High Dynamic Range Displays" SID 2019, College of Optics and Photonics, University of Central Florida, AU Optronics Corporation, Hsinchu, Taiwan
Binyi Zheng, et. al., "An Advanced High-Dynamic-Range LCD for Smartphones", SID 2019, Xiamen Tianma Microelectronics Co., Ltd

Backlight Unit

Mini-LEDs for Micro Display (LCoS, AUO)

Active Matrix Driving using LTPS TFT Backplane for 1,000 PPI VR LCD

- Local dimming function and switchable VR modes, high current → better contrast ratio and less motion blur, brightness Max. 130,000 nits (Normal 12,000 nits)
- Optimization of design for brightness vs. current result in IR Drop by increasing the number of mini-LEDs

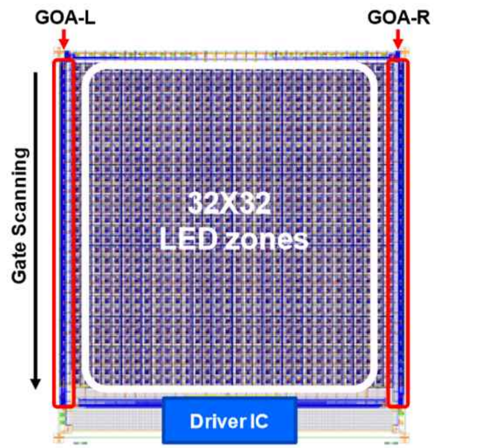


Figure 1. A schematic of AM mini-LED backlight of 32x32 LED zones.

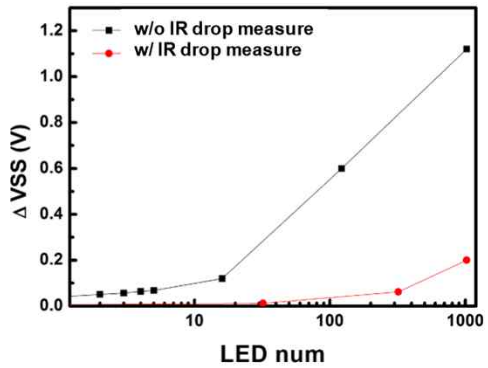


Figure 5. Improve of IR drop on AM mini-LED backlights.

	w/o action	Action 1	Action 1+2
Max. Current (mA)	112	730	1200
Max. brightness (nits)	10750	93308	130495
Current Efficiency (nit/mA)	96	128	108

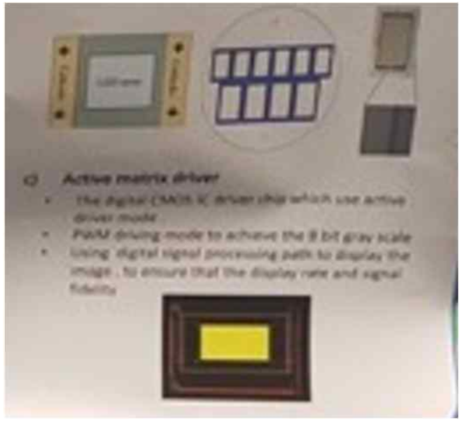
Figure 6. A backplane of AM mini-LED with LEDs.

Figure 7. A 1000PPI VR LCD module with AM mini-LED embedded.

Reference : Yang-En Wu, et. al., "Active Matrix Mini-LED Backlights for 1000PPI VR LCD " SID 2019, AU Optronics Corporation, Hsinchu, Taiwan

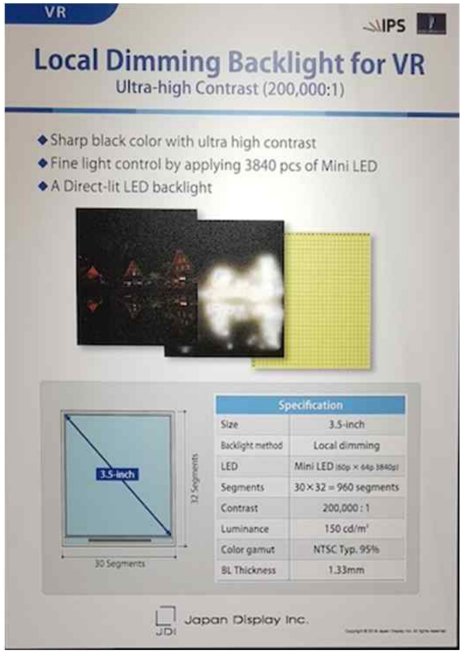
Backlight Unit

Pennsylvania State Univ. : Micro Display



CSOT : Smartphone, Automotive, Monitor

JDI : Micro Display



TIANMA : Micro Display

High Resolution & Active Matrix

Active Driving → LTPS / Oxide TFT Vs. Micro IC

- Automotive Product for High Reliability

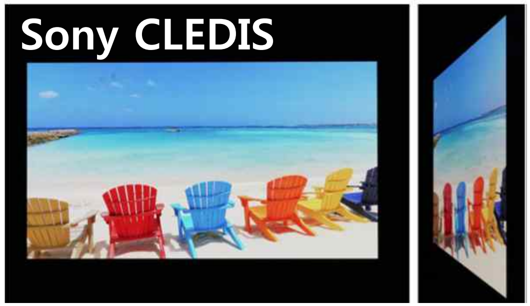
SID 2018

- 8″ micro-LED Display
- LTPS TFT B/P
- 169 ppi (chip size : 30um)
- Full-color : Blue LED + Color conversion mat'l

- 5.1″ full-color display
- 8 um x 15 um chip, 70 ppi
- micro IC for active matrix driving

SID 2019

-12.1″, 700 nits



-1,000 nits
- 20 PPI

Reference : H.M Kim, et. al., "10 μm Pixel, Quantum-dots Color Conversion Layer for High Resolution and Full Color Active Matrix Micro-LED Display" SID 2019

03 기술동향

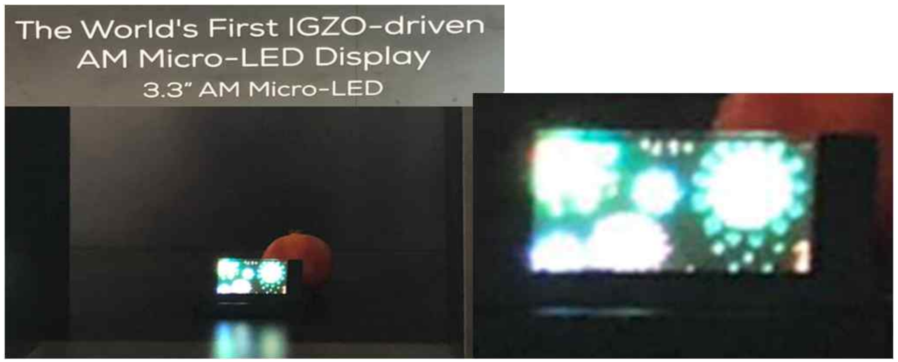
High Resolution & Active Matrix SID 2019

Active Driving → LTPS / Oxide TFT Vs. Micro IC

[ITRI]

- 40 PPI, 6 Cm X 10 Cm
- Micro LED on PCB and PI.
- Direct transferring RGB Micro LED chips to PCB backplane in volume

[NATIONSTAR]



- 3.5" full color transparent.
- IGZO glass backplane with active matrix driven solution.

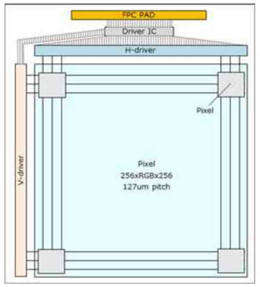
03 기술동향

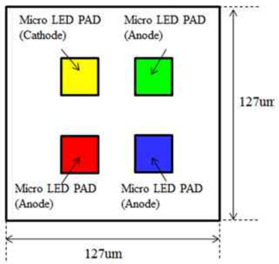
High Resolution & Active Matrix

Active Driving : LTPS TFT, 200 PPI, 1.8 inch size for HUD or AR

- **A dot pitch of 127 x 127 μm (200 ppi) by optimizing the layout of LED-mounted pads of each of RGB according to the pixel size, and also by optimizing the pattern layout of the pixel circuit and peripheral circuit formed by LTPS in the lower layer of each LED PAD.**

Category	Item	Condition	Result	Remark
Display spec.	Number of dots	-	256 x 256 RGB	
	Dot pitch	-	127 x 127 μm	200 ppi
	Display size	-	1.8 inch	
	Active area	-	32.5 x 32.5 mm	
	Optical device	-	Micro LED	RGB independently emission
Optical spec.	Brightness	25 degree C White image	984 cd/m^2	
	Contrast	25 degree C	More than 1,000,000 : 1	
	Gray scale	-	8 bit full color	
	Color reproducibility	984 cd/m^2 White = D65	117 % 88 %	NTSC ratio Rec.2020 ratio
	Response time	-30 to 80 degree C	Less than 1 ms	
	Viewing angle	Contrast > 10,000	More than 178 degree	
Electronic spec.	Operating temperature	-	-30 to 80 degree C	
	Frame rate	-30 to 80 degree C	240 Hz	



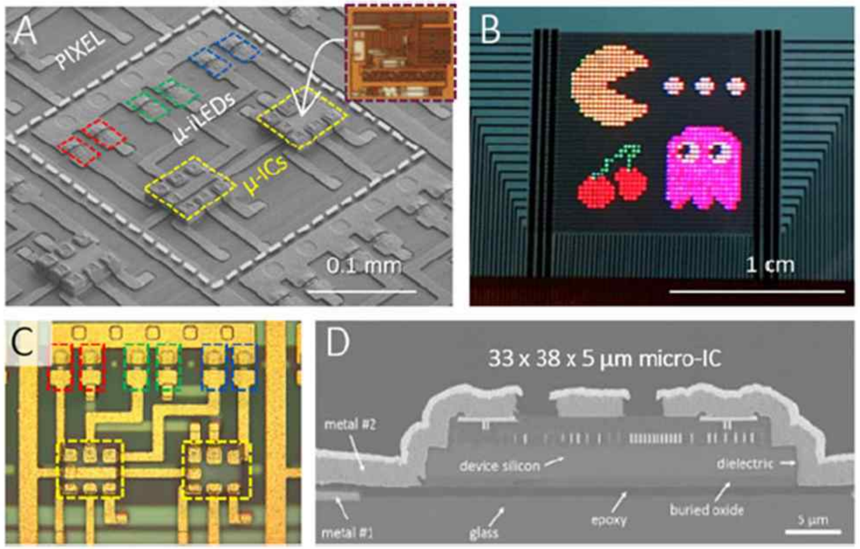


Reference : Sho Nakamitsu, et. al., "High PPI Micro LED Display for Small and Medium Size " SID 2019, Kyocera Corporation, Yasu, Japan

High Resolution & Active Matrix

Active Driving → Micro IC

- **Carry out selective pick-Transfer-Place and bonding process on high precision patterned backplane and then the passivation layer is deposited on them**
- **Through the sputtering and photolithography process, the interconnect vias and traces are selectively formed**



X-celeprint

- 5.1″ full-color display
- 8 um x 15 um chip, 70 ppi
- micro IC for active matrix driving
- stamp size : 15mm (yield : 99.99%)

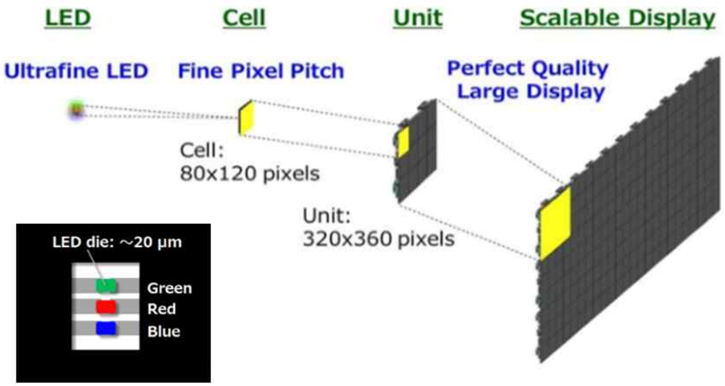
Source : X-celeprint patent and papers

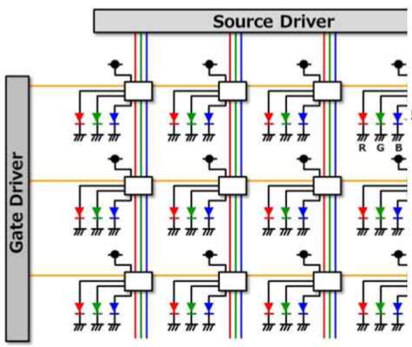
03 기술동향

High Resolution & Active Matrix

Active Driving → Micro IC (Sony CLEDIS)

- **Active matrix driving : Integrating RGB micro LEDs and a micro IC in each pixel**
  - ➢ **The passive-matrix driving in a large scale display system → High current densities, Impedance mismatching, Cross talks between lines → These issues give rise to limitations such as resolution, brightness, reliability, and motion picture quality.**





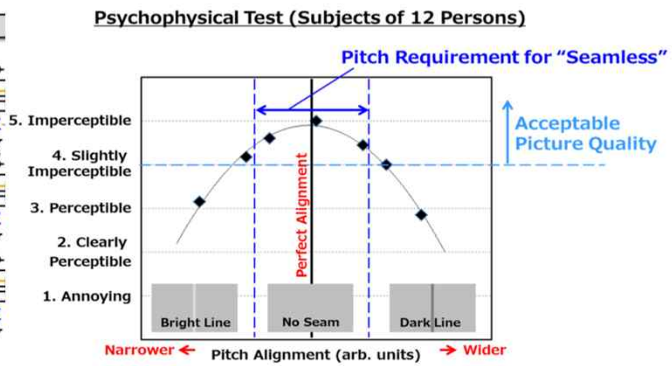


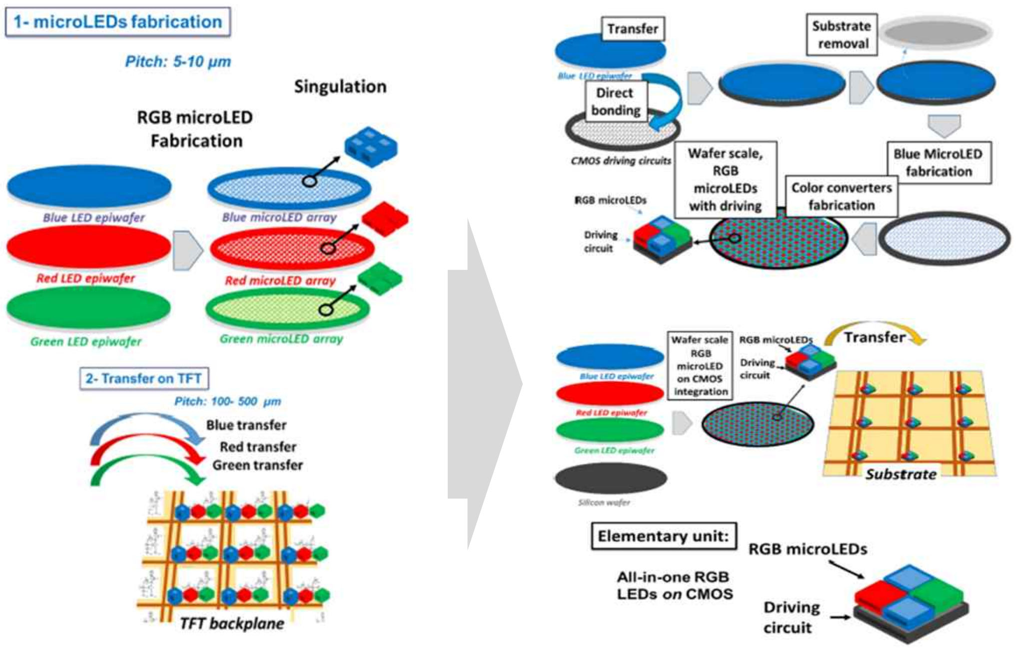
Table I. Features of Crystal LED display system.

Brightness	1,000 cd/m^2
Pixel Pitch	1.26 mm
Native Color Space	140 % of sRGB (u'v')
Frame Rate	up to 120 fps
Viewing Angle	almost 180 degrees

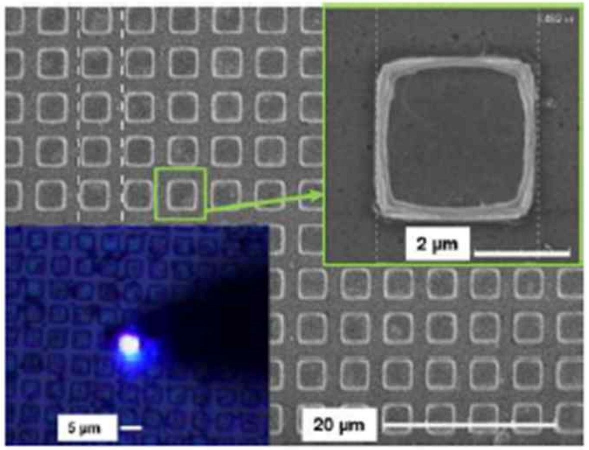
Reference : Goshi Biwa, et. al., "Technologies for the Crystal LED Display System" SID 2019, Sony Corporation, Tokyo, Japan Sony Semiconductor Solutions Corporation, Kanagawa, Japan

High Resolution & Active Matrix

- **Active Driving → CMOS Circuit Substrate likely Micro IC (CEA-LETI)**
  - **AM-WLP(Wafer Level PKG) : RGB Chip on a CMOS sub**
    - ➢ **Active Matrix Solution → The receiving part is no more a TFT B/P → a simple, low-cost receiving substrate (Transfer Printing Process, The Kinds of B/P Loss etc.)**
    - ➢ **CMOS Driving provide more HDR (High Dynamic Range) than TFT → High Quality Brightness**



Non-lithographic techniques → Low cost
Free of TFT Process → No size limit
Rigid/flexible Material → Freedom of material

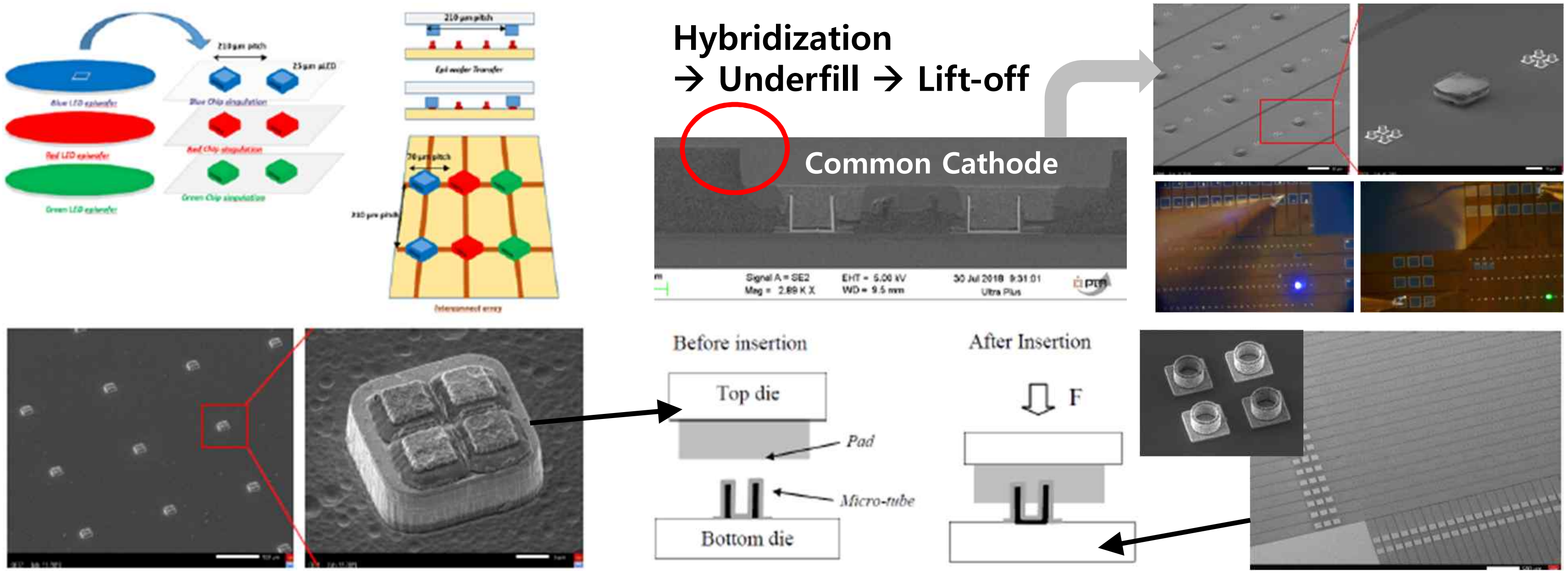


Reference : F. Templier, et. al., "A New Approach for Fabricating High-Performance MicroLED Displays, Grenoble Université Alpes, CEA-LETI, France

High Resolution & Active Matrix

Microtube Interconnection (CEA-LETI, 100 ~ 120PPI RGB Solution)

- Growth of blue & green Epi. in a silicone wafer (4”, 25µm× 25µm × 5µm)
  - ➢ Fabrication of a blue and a green prototype with 40 x 40 pixels, 210 µm pitch on passive matrix.
- Passive matrix by using conventional CMOS process on 8” wafers (Tube Structure)
- Hybridization → Remove Epi. Sub. → Repeat Green MicroLEDs



Reference Jeannet Bernard, et. al., “MicroLED Displays based on Transfer with Microtubes Interconnections, Grenoble Université Alpes, CEA-LETI, France

04 Conclusion

Mega Trend : Large Display, Automotive, Micro Display

Micro LED Cost Reduction
→ Next Generation Display, Post-OLED

Currently, Mini-LED BLU Market is started
: Mobile → AR/VR → TVs

Pixel Colorization using QD
→ Reduction solution : increase of cost and failure probability for transfer printing process