μLED(뮬레드) 산업동향

2017. 10

μLED Display & Convergence Research Center
Korea Photonics Technology Institute
Y.W. Kim

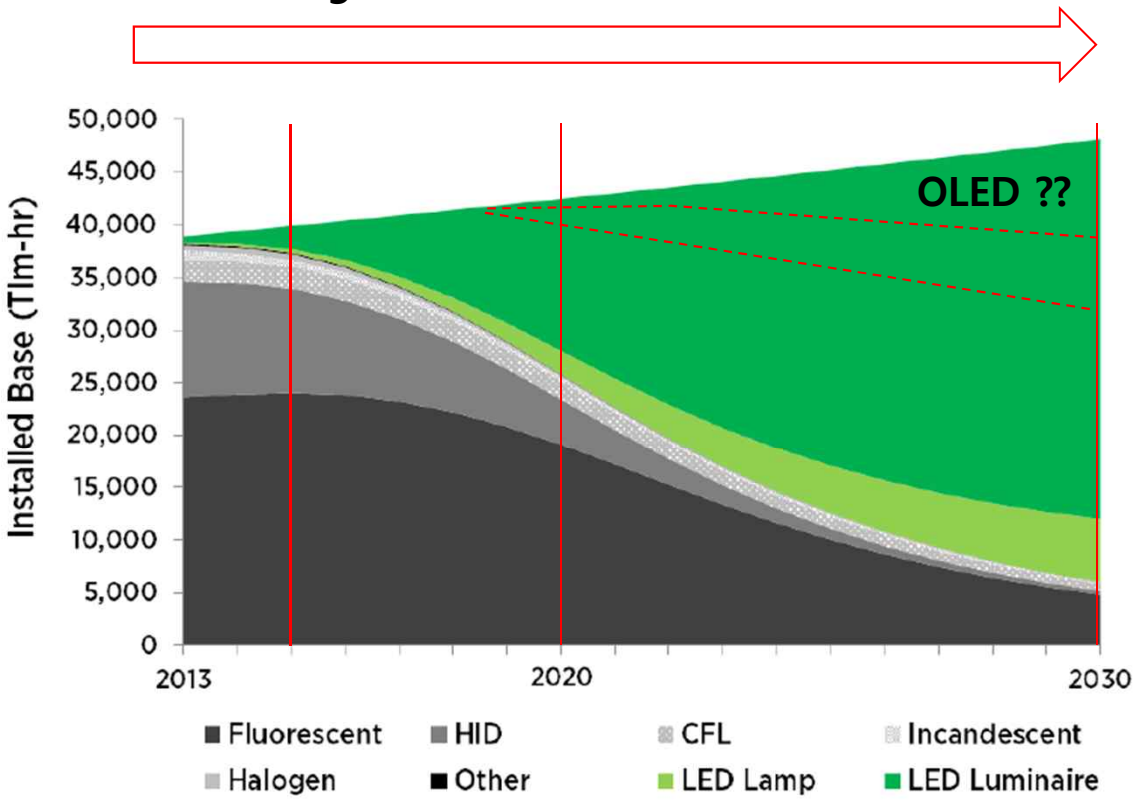
LED Display I

Application : Mobile(`05) → BLU(`13) → Lighting (~`30)→ Convergence

Past Issue

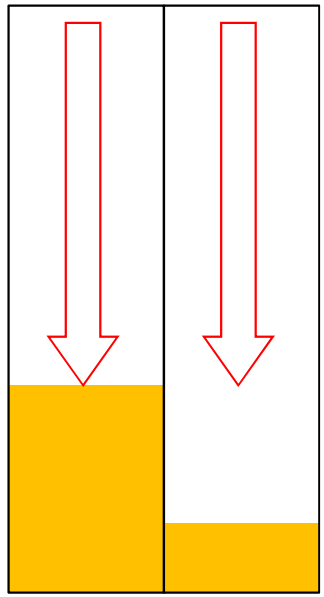
- Performances, Cost Effectiveness, New Applications

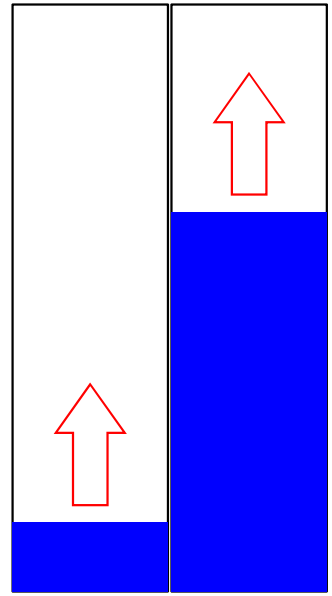
Long-Term Technical & Business Plan



Red Ocean

< BLU, Lightings >





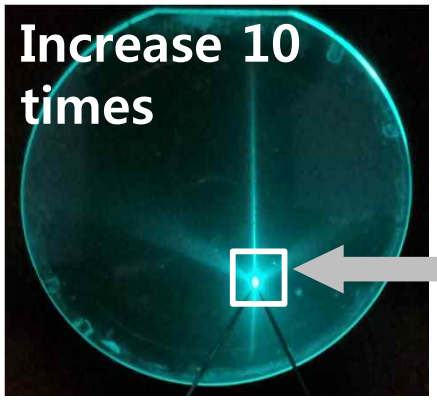
<Convergence>

※ Reference : DOE SSL R&D 2016

LED Industry II

Micro LED for Service-Oriented Application

Mega Trend



Display, Bio-medical , Transportation

Micro LED
0.001 ~ 0.1 mm

Display : 2 B x 0.1 ~ 9 M (μLEDs) = 20~1,800 trillion unit

Lighting : 50 Billion lamp x 10 LEDs =0.5 trillion unit

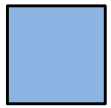
TV/전광판

모바일

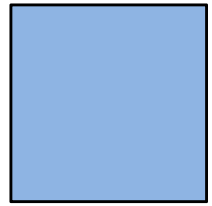
웨어러블

Declining Industry
(In Korea)

BLU
Mid-Size
0.5 mm



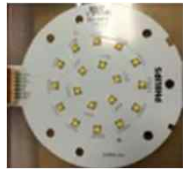
조명
Large-Size
1 mm

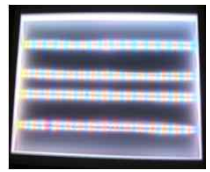


(Lighting) Low Growth

(BLU) OLED & Low Cost

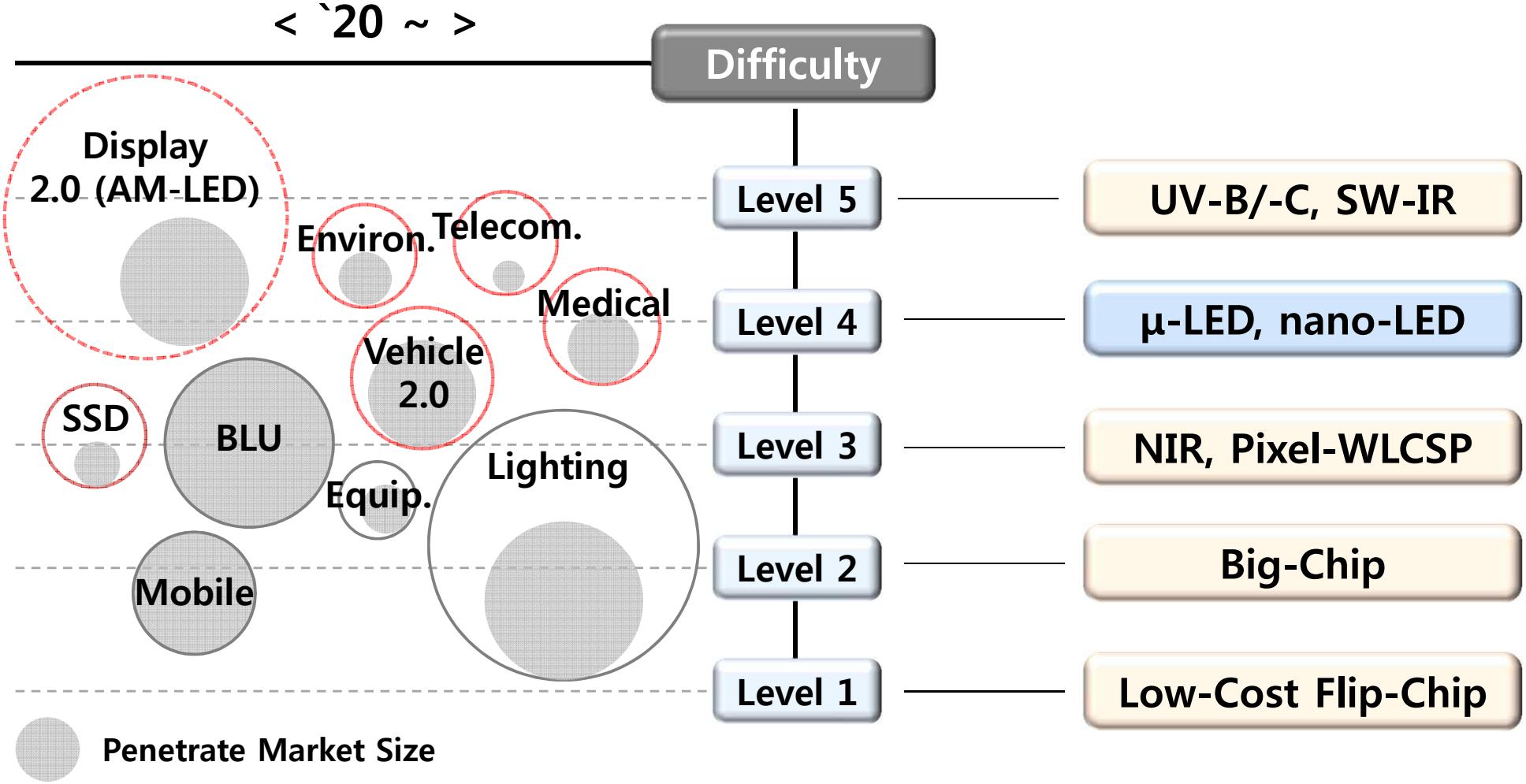
(Market) Encroachment





LED Industry III

Great Attractive Applications : Next Generation Display



※ SSD : Security-Safety & Defense, AM-LED : Active Matrix LED

LED Industry IV

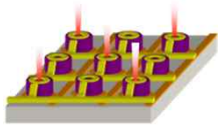
미래산업 Trend →Big Data, 무인자동차, 3D 프린터, 드론 등

소형화, 집적화, 유연화

서비스 산업에 적합한 LED 기술

< LED Display>

<LED + Sensor>



< LED통신 → IoT>

ICT 융합

바이오 /헬스

에너지

<Big Data 산업>

스마트
쓰레기통, 커피메이커,
약통, 우산, 거울 …
자동검진, 약제조 …

가상현실
글래스, 콘택렌즈

<무인자율주행 기기>

인공지능 컴퓨터
Radar/Lidar/Stereo
Camera, Scanner

센서
환경, 위치, 거리, 농도,
조도 …

4차산업혁명 시대를 맞이하여 산업부 12대 신산업 재편

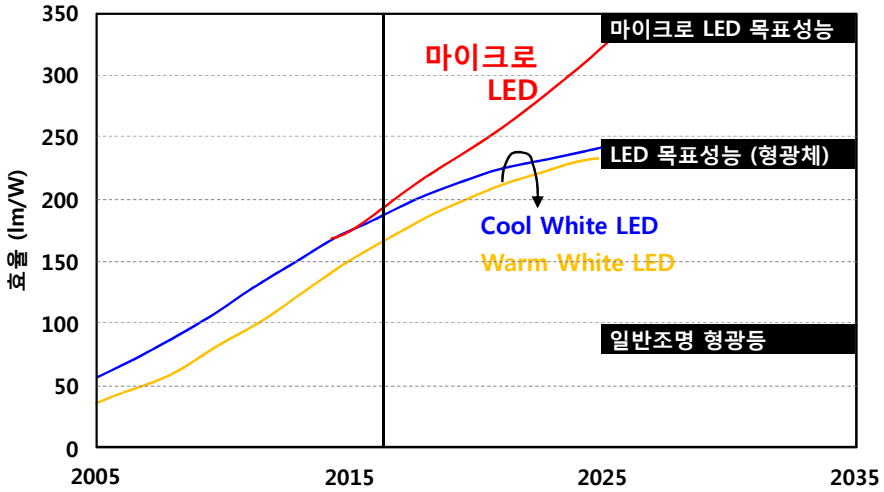
- **세계적 수준의 IT 인프라와 제조기반, 에너지산업 여건 등 보유강점을 활용 12대 신산업 창출, 산업구조로 고도화 ('18년까지 80조원 투자 추진)**
  - **글로벌 시장전망, 국내기업들의 민간투자 계획 분석, 4대 트렌드 영향 등을 종합적으로 고려하여 12대 신산업 청사진 제시**

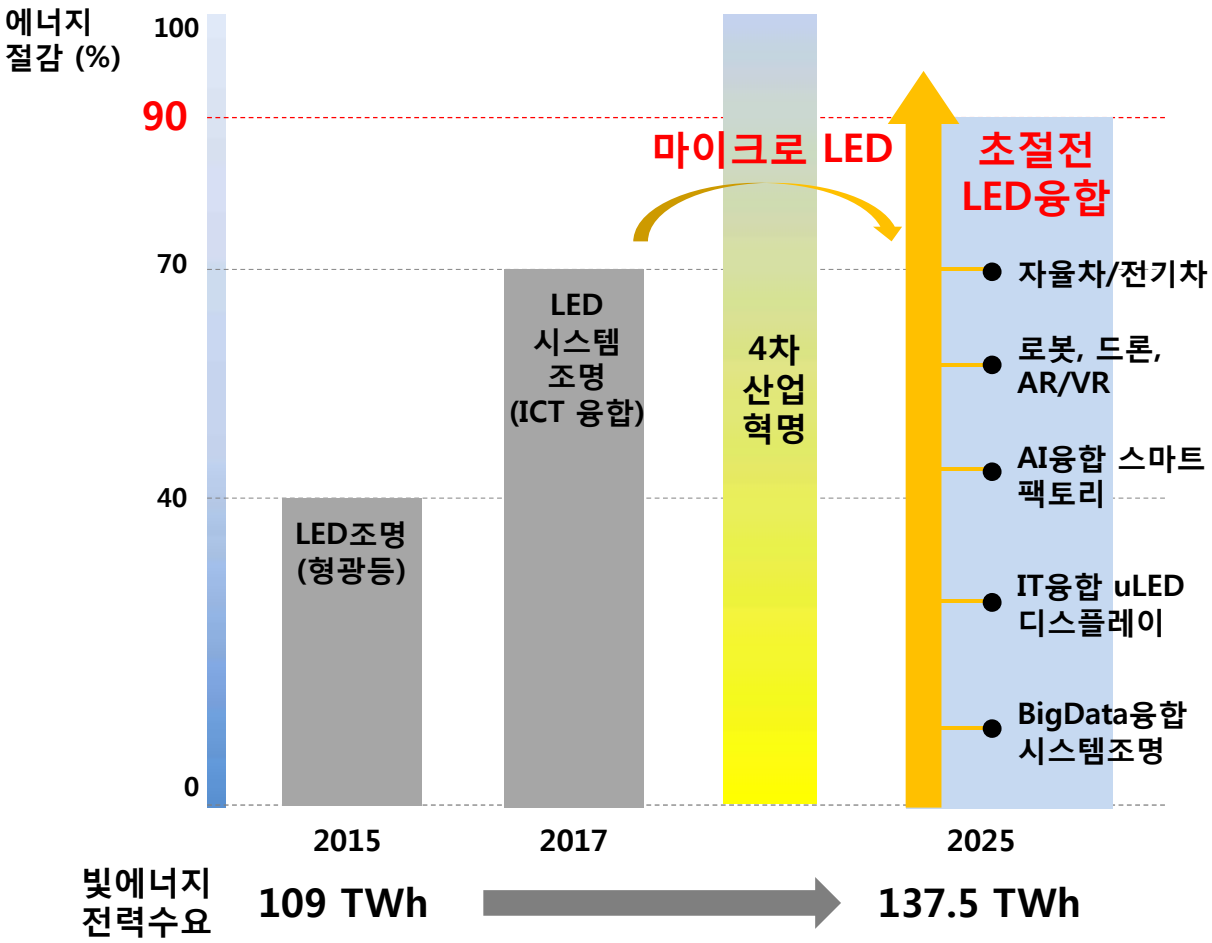
분야	연계성	연계제품	에너지절감
전기.자율차	◎	마이크로 LED 조명, 헤드램프	◎
스마트선박	○	고효율 방폭등, 안전센서 적외선 LED	◎
IoT가전	○	LED통신, 시스템조명	◎
로봇	△	충전형 마이크로 LED 조명	○
바이오헬스	○	치료용 LED	×
항공.드론	○	충전형 마이크로 LED 조명	◎
프리미엄 소비재	×	-	×
에너지신산업	◎	시스템조명, 스마트공장조명, LED전광판	◎
첨단신소재	△	LED제조공정용 소재	×
AR/VR	◎	스마트글래스용 디스플레이	◎
차세대디스플레이	◎	퍼블릭/스트레쳐블/밴더블 디스플레이	◎
차세대 반도체	×	-	×

마이크로 LED의 효율은 LED 대비 20% 이상, 유연제품 유망

환경정책

- **'15년 UN 파리 기후변화 협약**
  - ➢ 산업통상자원부 등 7개 부처와 200여명의 산·학·연 전문가 합동으로 이행 방안 마련
- **환경부는 자동차 연비 및 온실가스 규제를 대폭 강화**
  - ➢ 20년까지 이산화탄소 배출 기준이 97 g/Km 제한

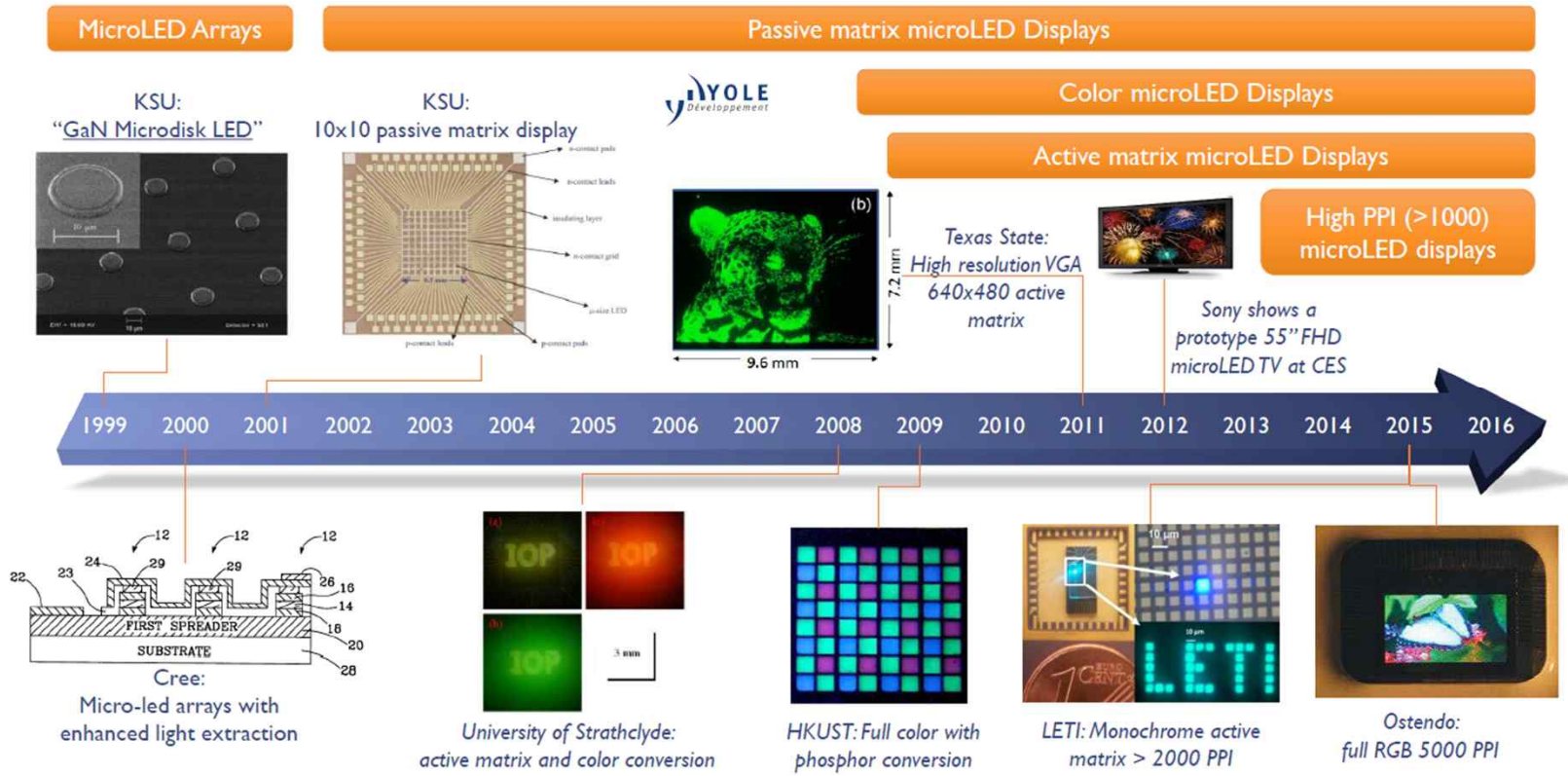




µLED I

History

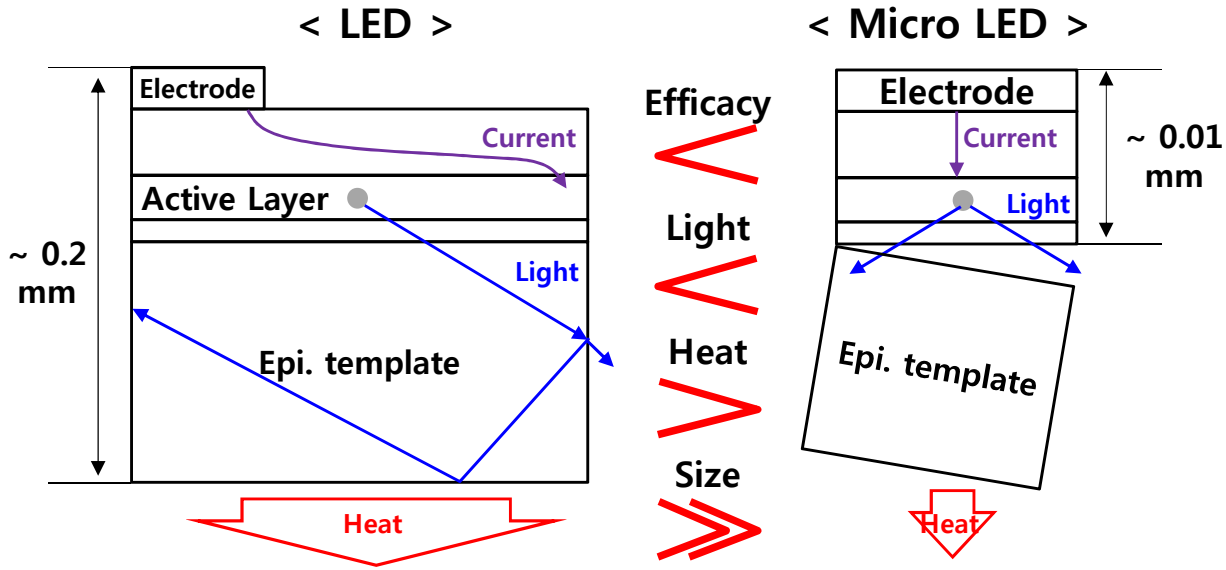
- **Miniaturization technology in the late `90 → Display & Wearable appliances**
  - **Professor Jiang, University of Kansas Reported for the first time in Applied Physics**
  - **Micro LED and Transfer Printing Technologies Strathclyde Univ., and Rogers Research Group, UCIC in 2008**
  - **The research for the commercialization had been accelerated in the field of display and AR/VR**

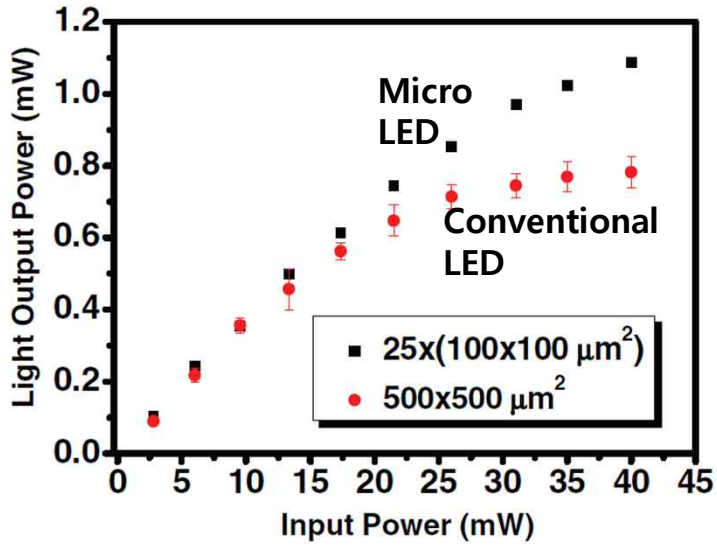


Advantages : High Efficiency, Low Thermal Effect

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



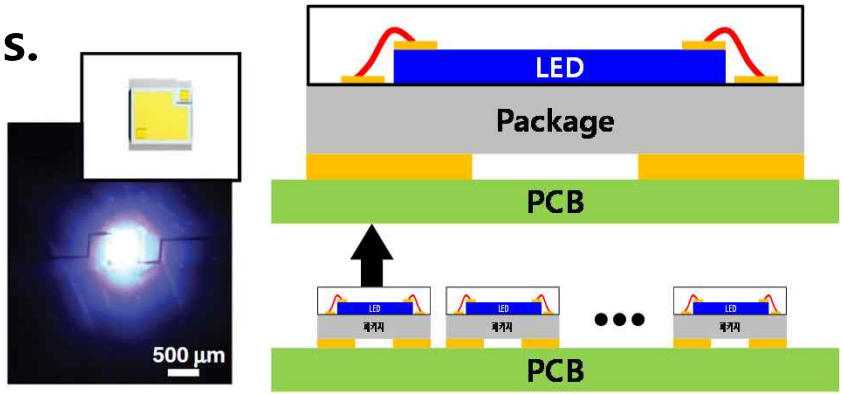


Reference : T.Kim, et.al., "High-Effi ciency, Microscale GaN Light-Emitting Diodes and Their Thermal Properties on Unusual Substrates" small 2012, 8, No.11, 1643~1649

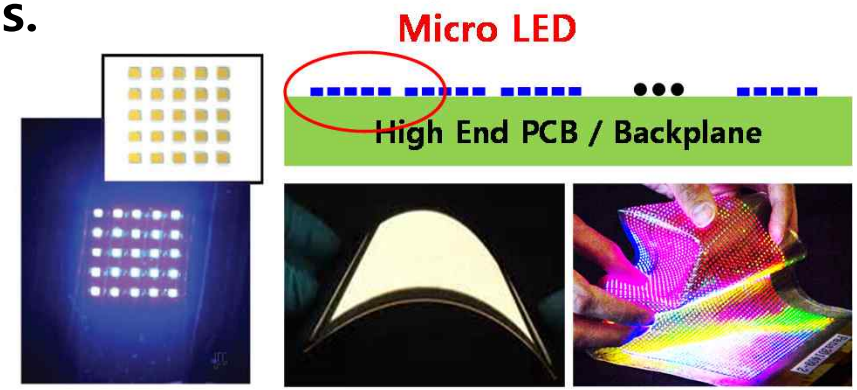
Applications : Display, Automotive, Lightings

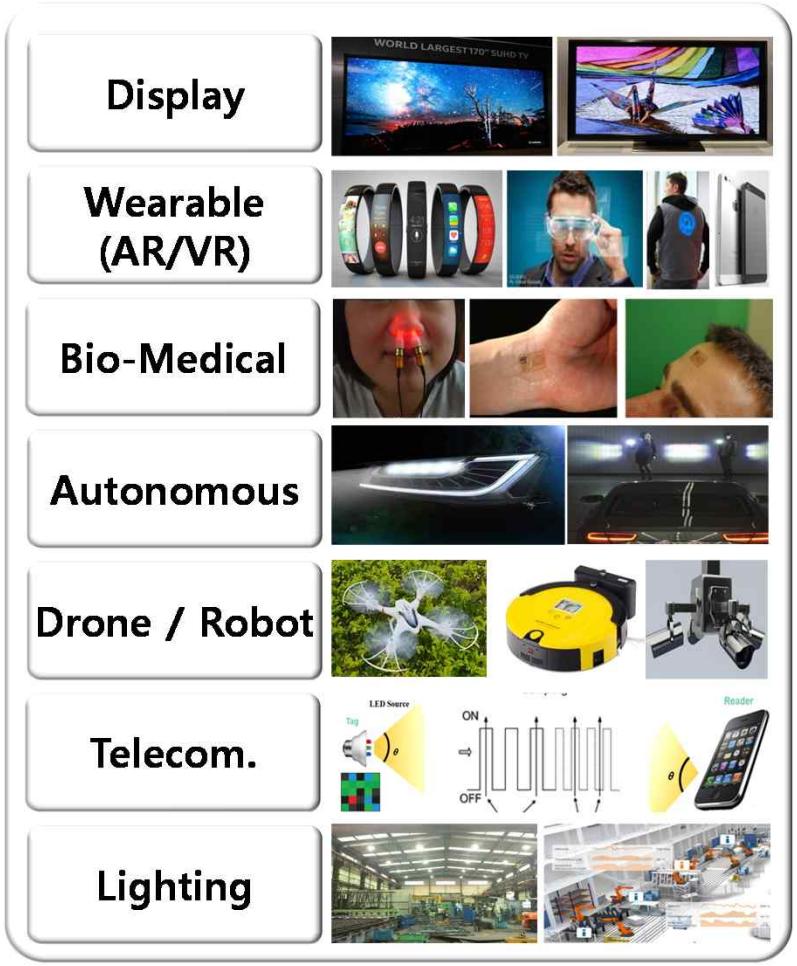
- Core Technologies of Micro LED are compatibly Not only microminiaturization, but also Integration & Flexibilization for applications

Cons.



Pros.

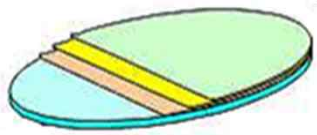




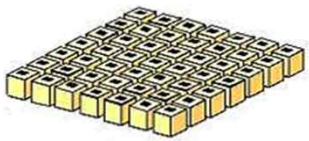
Transition of Fabrication Process : 5 Step → 3 Step

< Conventional 5 Step >

- Epi.



- Chip



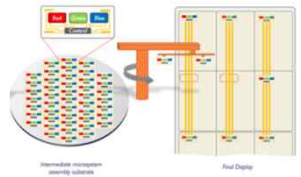
- PKG

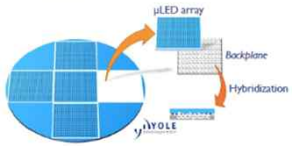
- Module

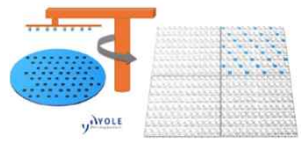
- Applications

< Micro LED 3 Step >

- Epi. — Sapphire (LLO), Silicone (CLO) template for separation method
- Panel & Module (Integrated Process)
  - Front-end — Chip Process for Transfer Printing
  - Back-end — Applications
    - Display
    - AR/VR
    - Wearable
    - Vehicle
    - Lighting



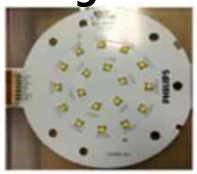




µLED V

소형화 / 저가격화 → 공정단순화, 통합화, 집적화 → 유연화 : µ-LED

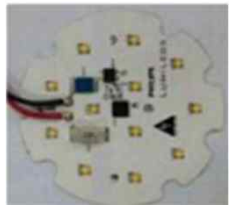
LED Engine



Control Gear (SMPS)

< 현재 >

LED Engine +Optic Lens + Heatsink

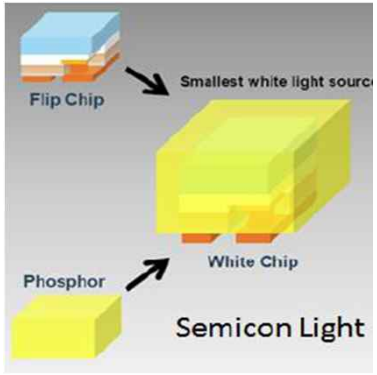


Ceramic

Lead Frame

COB (PCB)

WLP/CSP (Lead Frameless) = LED Engine



< 미래 >

유연 면조명

GaN on Silicone → 대면적화

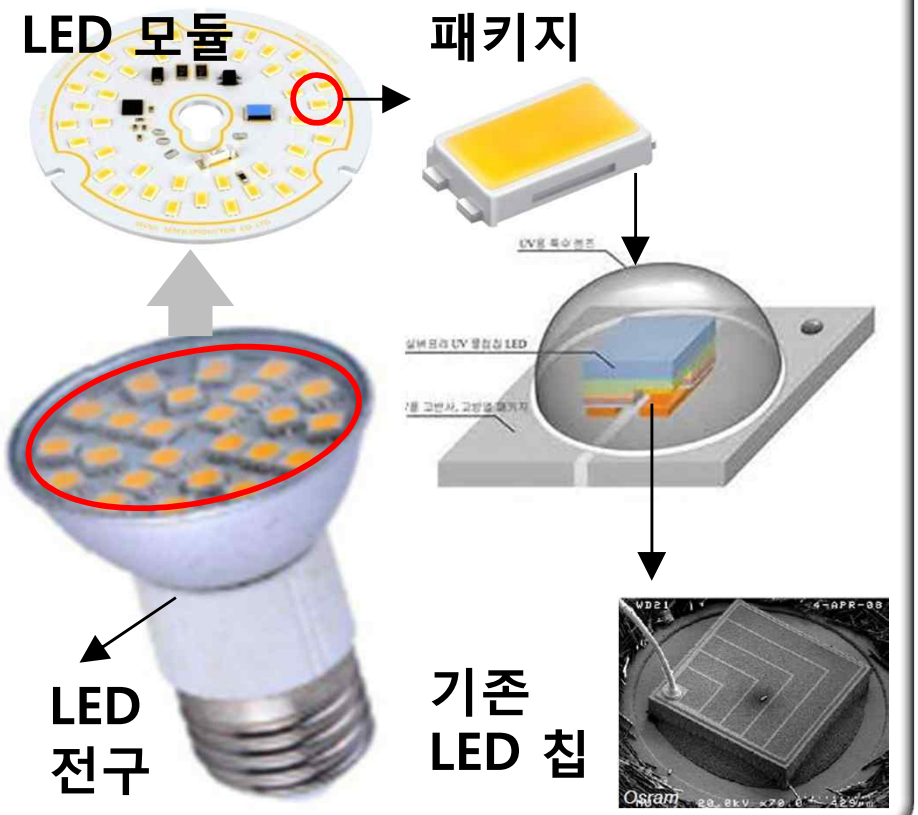
+

Micro LED

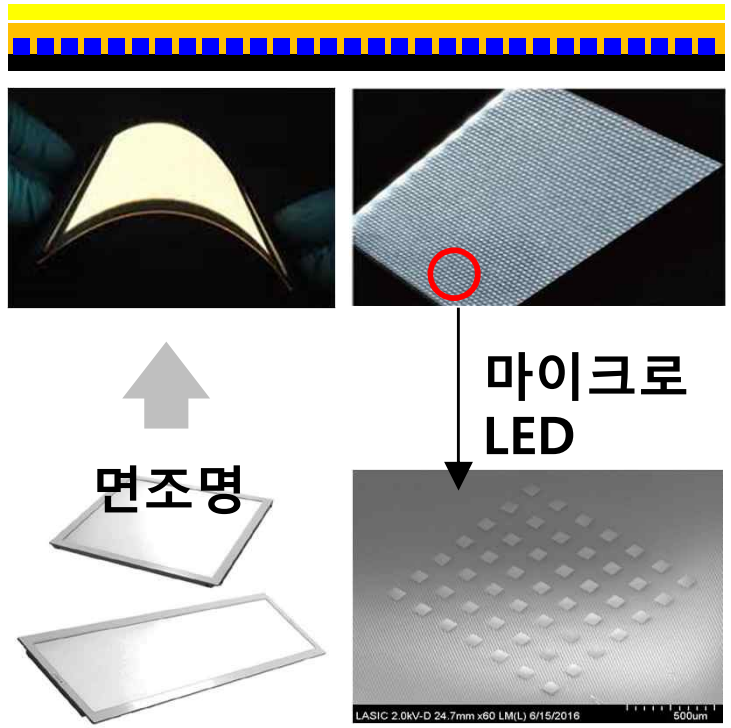
※ 자료참조 : DOE SSL R&D Plan 2015

스마트 홈, 공장, 시스템조명 등 ICT 융합분야로 발전

< 기존 LED >



< 마이크로 LED >

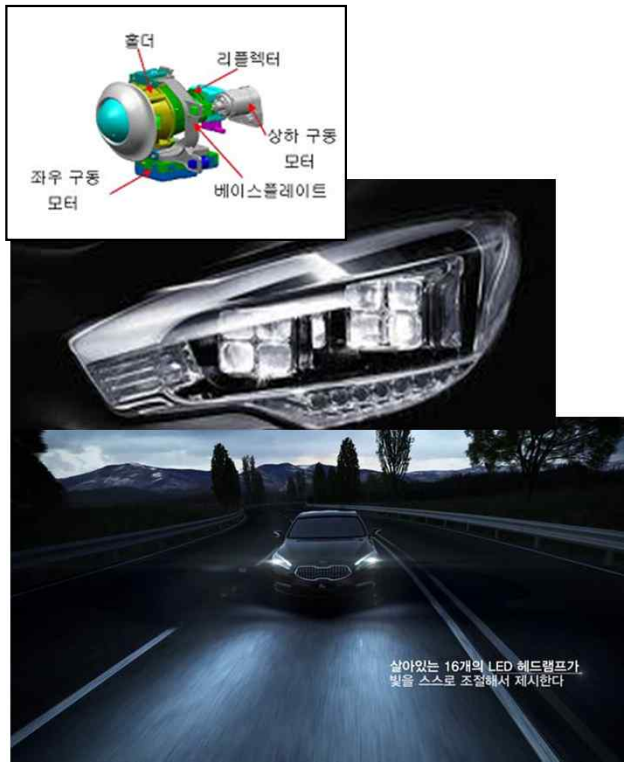


µLED V

조사면에 대한 픽셀별 분리 → 최대 1024 Pixel (마이크로 LED)

- 안전운행 (CCD 센서 + 마이크로 LED/광학계)
  - CMOS 스위칭 소자와 마이크로 LED 연동하여 CCD에 감지된 사람/차량 위치에 대한 광도 조절
  - ISAL 2015 (International Symposium on Automotive Lighting)에서 OSRAM사가 발표

Actuator based AFLS

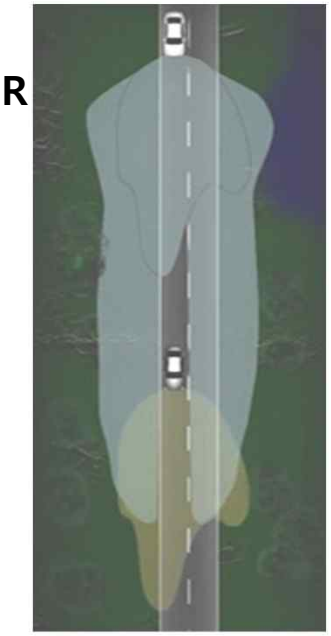


LED matrix AFLS

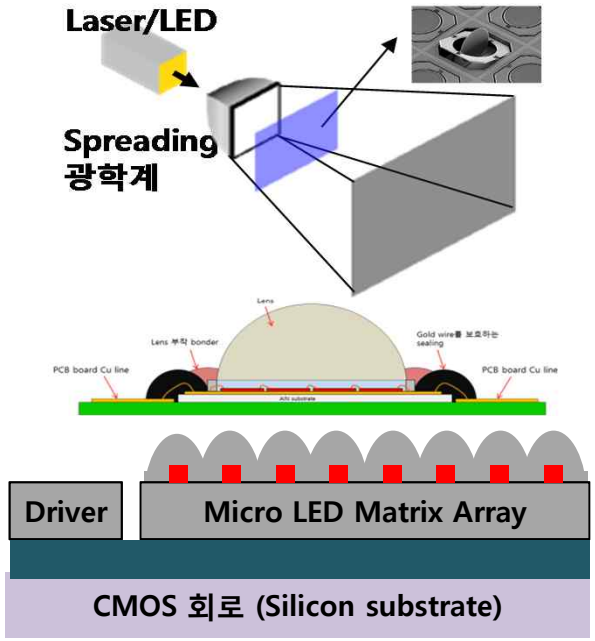
OSRAM
INFINEON
FRAUNHOFER
HELLA
DAIMLER

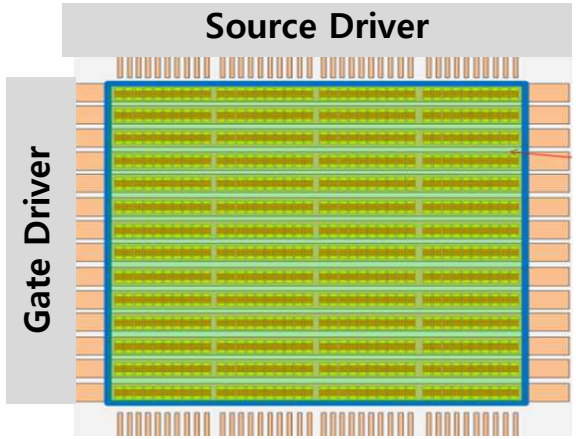
+

HBA (High Beam Assistant)



Adaptive Matrix Beam : 적외선→ADAS, 가시광→Head Lamp

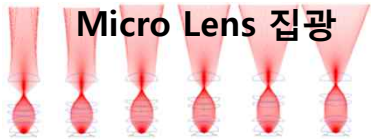




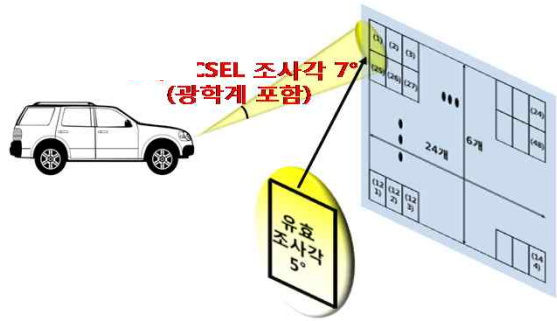
고신뢰성 접합구조

- Eutectic / 에폭시솔더 본딩 → 방열특성 확보, CTE 비정합에 의한 신뢰성 저하 방지

마이크로 렌즈



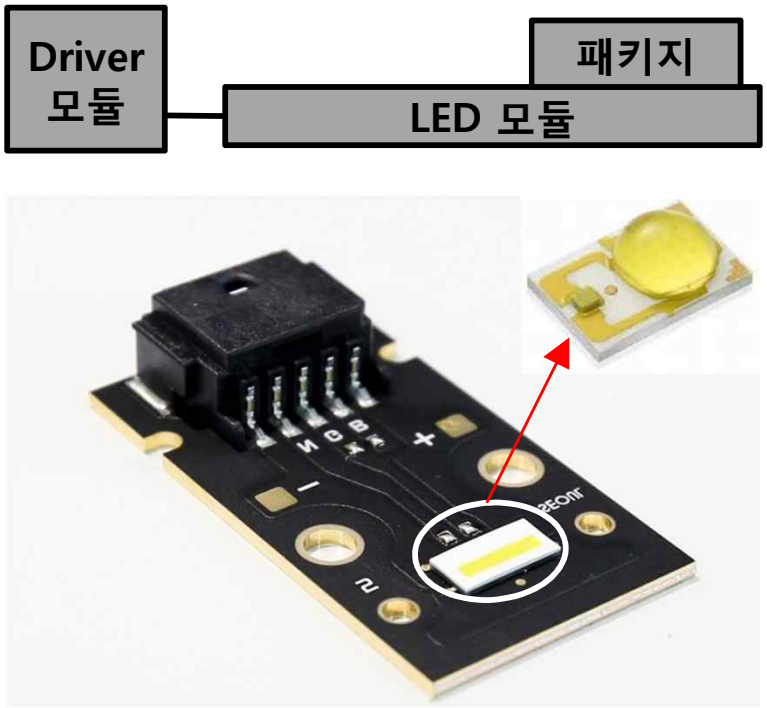
Pixel Array 배열 구조
120도/30도 이상



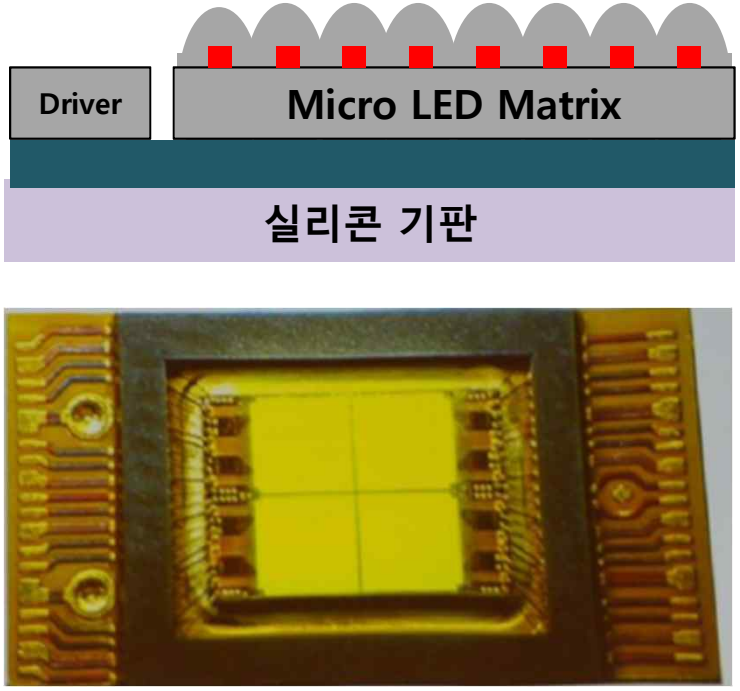
제조방법의 변화 → 장비/공정/응용제품 트렌드 변화

- 기존 5단계에서 3단계 공정으로 변화

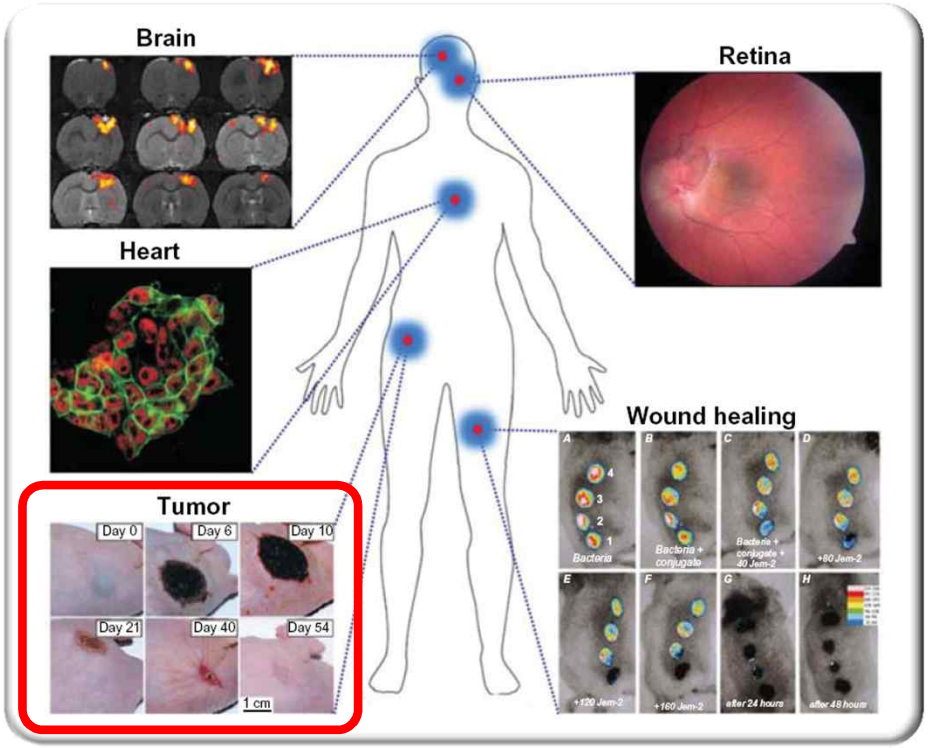
< 기존 LED >



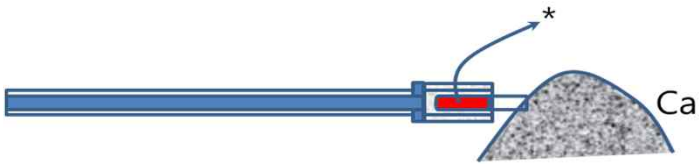
< 마이크로 LED >

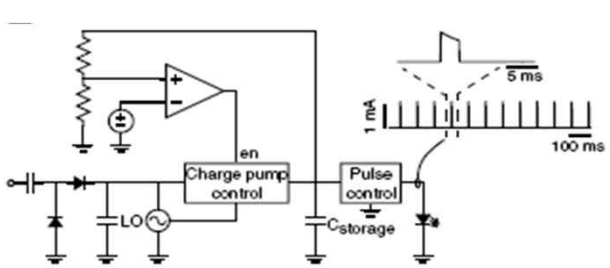


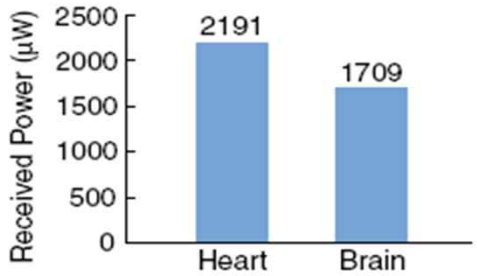
Micro LED의 인체 삽입 → Optogenetics (신경/종양)



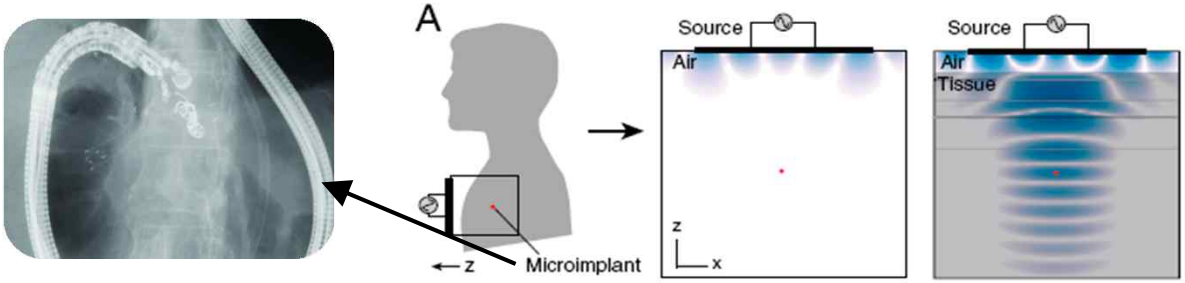
<RF 무선전력전송 집적형 Micro-LED>

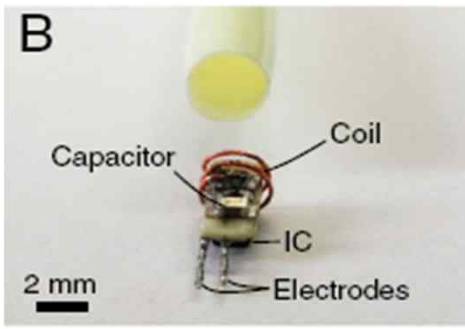


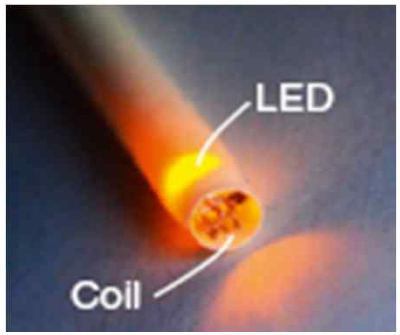




<체내 이식형 Micro-LED 모듈>





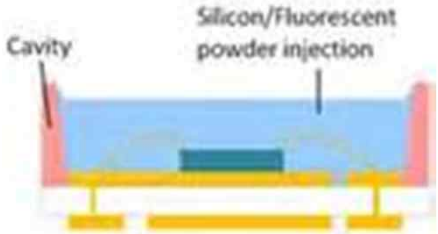


자료참조 : Min Koo et al., "Biointegrated flexible inorganic light emitting diodes", Nanobiosensors in Disease Diagnosis 2012, Rogers group, UIUC(Science, 2012), Melissa R. Warden , Jessica A. Cardin and Karl Deisseroth.,"Optical Neural Interfaces",

개인용 이동수단, 로봇, 드론 등

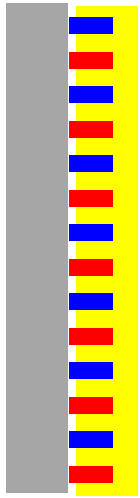
< 기존 LED >

1W COB LED



< 마이크로 LED >

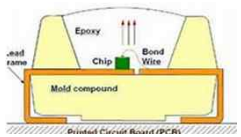
가시광
근적외선
마이크로
LED



충전식기기 (로봇/드론 등)

스마트워치, 글래스, e-skin, 패션

< 기존 LED >



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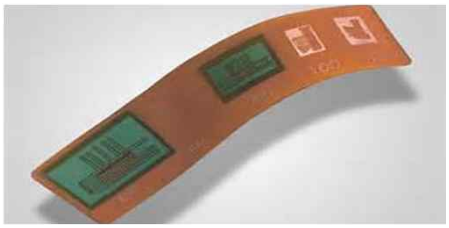
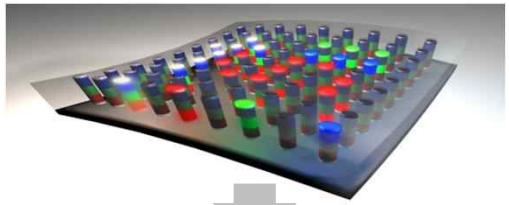


< 마이크로 LED >



Back Plane

TFT 회로 형성

성장기판

Back Plane

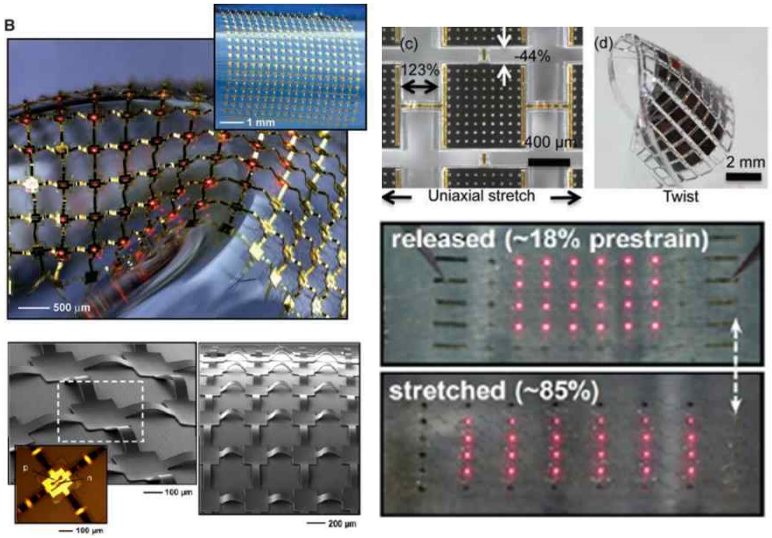
TFT 회로 형성

성장기판

µLED V

마이크로 LED 적용 (Lab. 수준) 기술개발 초기 단계 ➡ 대형화 적합 소재/공정 개발

< Rogers : 디스플레이, 태양전지 >



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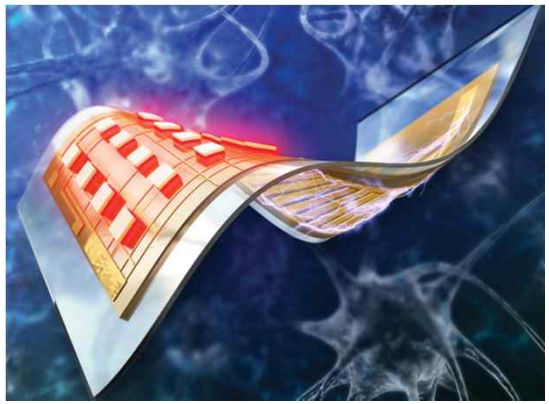
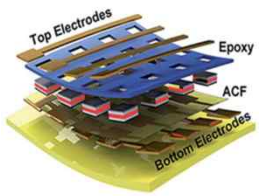
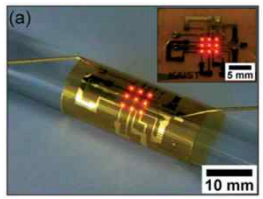
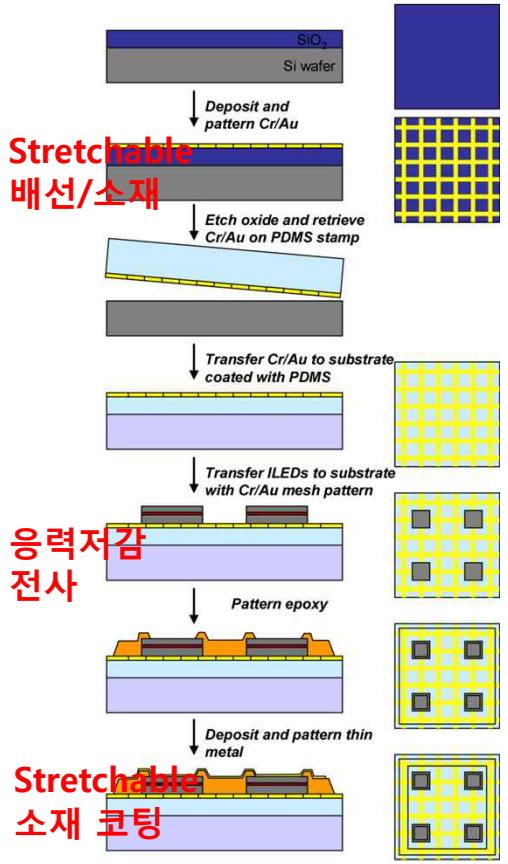






< 개발소재/공정 >



상용화를 위한 크기 확대 기술 개발

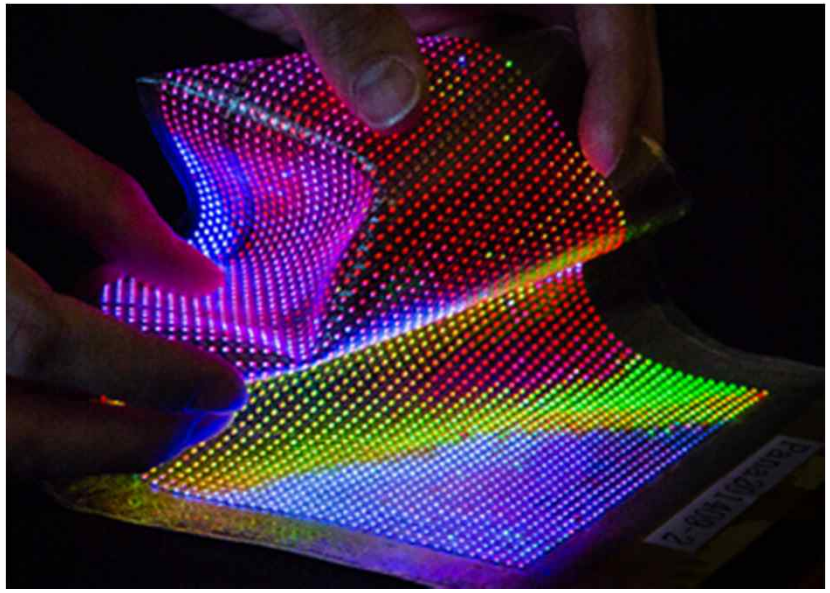
- → 마이크로 LED Stress 저감 전사 구조 : Low-Strain 보강 구조
- → Stretchable 기판 / 배선 구조 : Rubber (PDMS), 말굽구조, Trench 등
- → 절연층 형성 유연소재 / 공정 : 탄성체 코팅
- → 신축팽창 배선 전기적 안정성 구조 : 독립적 배선 유동/코팅

Sang-Il Park, et.al. , "Printed Assemblies of Inorganic Light-Emitting Diodes for Deformable and Semitransparent Displays", SCIENCE VOL 325 21 AUGUST 2009
Rak-Hwan Kim, et.al., Stretchable, Transparent Graphene Interconnects for Arrays of Microscale Inorganic Light Emitting Diodes on Rubber Substrates, Nano Lett. 2011, 11, 3881–3886
Chang Kyu Jeong. et.al., Self-powered fully-fl exible light-emitting system by fl exible energy harvester Energy & Environmental Science Energy Environ. Sci., 2014, 7, 4035

µLED V

IMID 2015

< IMEC Stretchable Display >



13 PPI, 200 nit, amorphous indium-gallium-zinc oxide (a-IGZO) TFT backplane

Apple

< MacRumors Apple Watch 3>

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Apple Watch May Switch to Micro-LED Display in Mid 2017 or Later

Friday June 24, 2016 8:01 am PDT by Joe Rossignol

Apple may switch to micro-LED displays for the Apple Watch in the second half of 2017 at the earliest, moving away from the current OLED technology used, according to supply chain sources for Taiwanese website *DigiTimes*.

The timeline suggests that the much-rumored Apple Watch 2 lineup expected to debut in the second half of 2016 will continue to have OLED displays, with the move towards micro-LED panels liking occurring in tandem with the tentatively named Apple Watch 3.

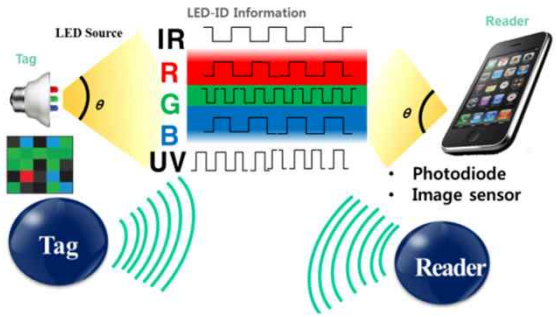
Micro-LED displays can be thinner and lighter and allow for improved color gamut, increased brightness, and higher resolutions. The panels do not require backlighting like traditional LCD displays, but they can be difficult and expensive to mass produce. Micro LEDs range in size from 1-micron to 100-micron.

Earlier this year, KGI Securities analyst Ming-Chi Kuo said the Apple Watch 2 will mainly feature internal improvements, with more significant form factor design changes not

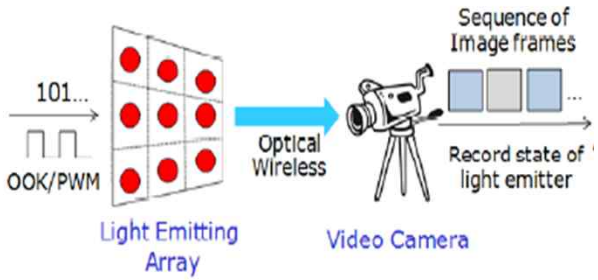
OCC / LED-ID / Li-Fi → Big Data / 콘텐츠 / 보안 서비스

- 무선통신체계의 문제점 및 위기/응급상황 발생시 대체 통신 수단 활용
  - 가시광통신 → 응용분야 조명,
  - OWC (Optical Wireless Communication) : IEEE 802.15.7r1 근거리무선통신 규격
  - LED-ID, OCC 및 Li-Fi 3가지 그룹으로 분류
    - LED-ID → 모바일 Application
    - OCC → 카메라 Application
    - Li-Fi → 고속송수신 (센서, UV ~ IR)

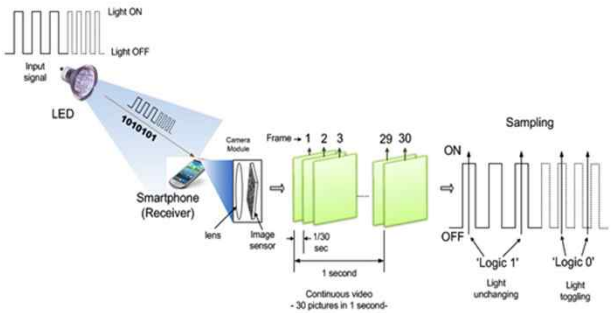
LED-ID



OCC



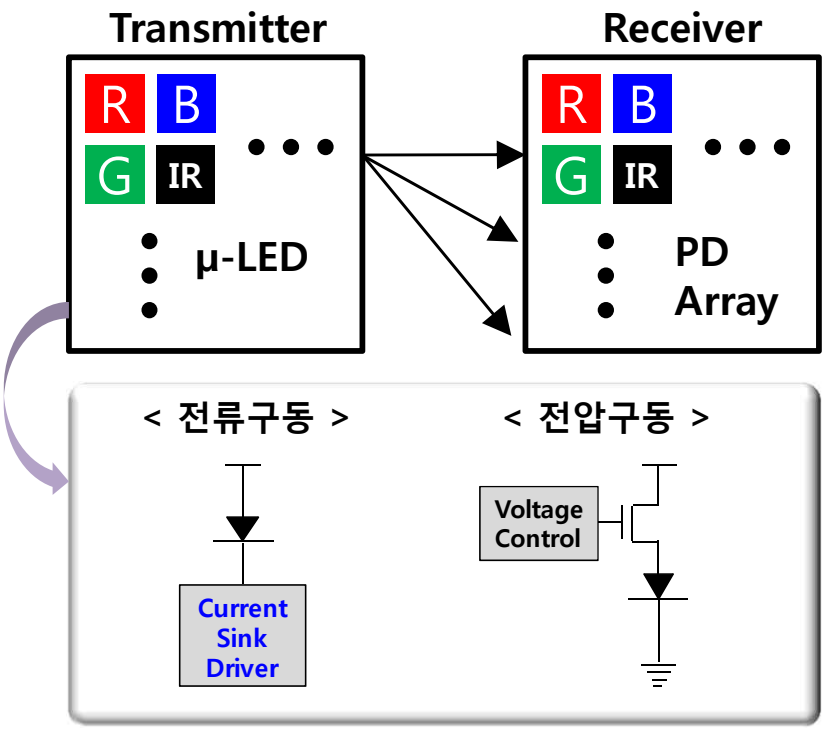
Li-Fi

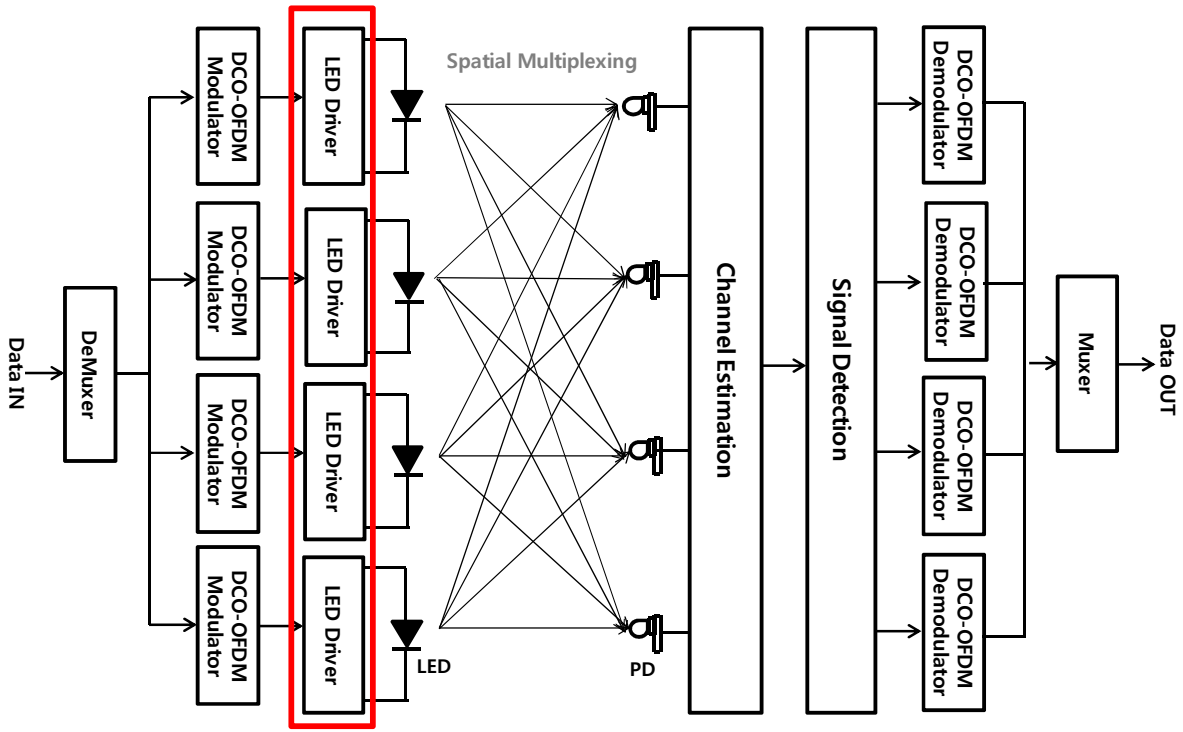


Micro LED 적용 → Switching Rate / Data Throughput 증가

대용량 Data 서비스

- µ-LED 파장 선택과 Transmitter용 광원별 진폭변조 (KOPTI Proto-Type)
- 0.01W µ-LED (400MHz) / DCO-OFDM / 4x4 MIMO 시스템
  - ➢ Throughput = OFDM/MIMO(30 bps/Hz) x (400MHz) x 파장 종류 4 x 진폭 Level 4 = 12Gbps x 4 x 4 → 192 Gbps

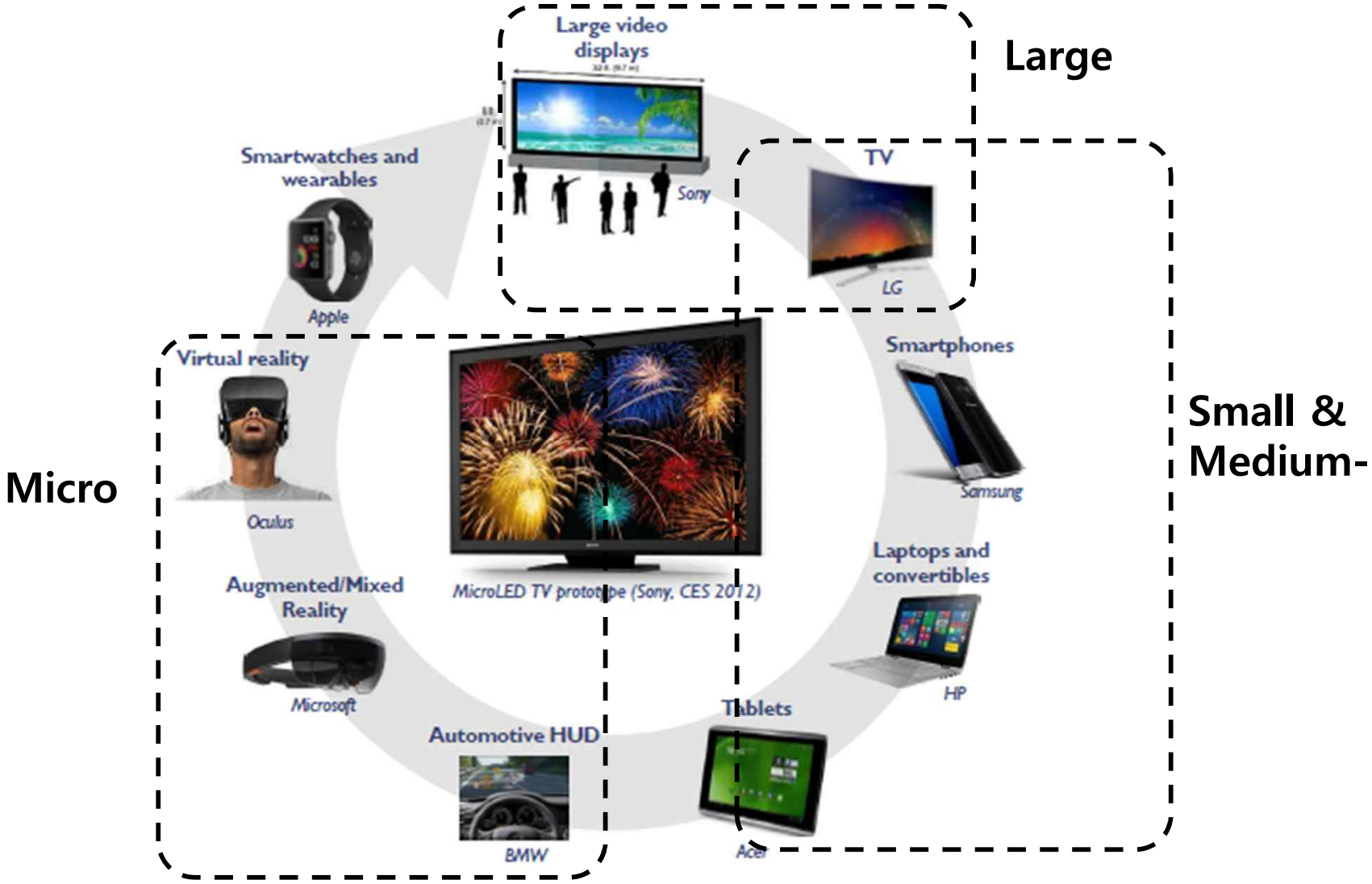




OFDM : Orthogonal frequency-division multiplexing (직교 주파수 분할 다중 방식), MIMO : Multi-Input Multi-Output

µLED Display I

Mobile(`00) → BLU(`07) → Lighting (`10)→ Display (~`12)



* Reference : Yole Development 2017

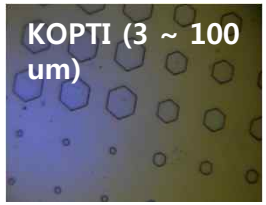
µLED Display II

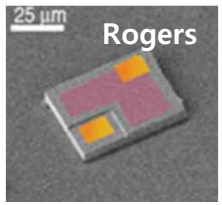
µLED → Display → Foldable, Bendable, Rollable, Stretchable …

<Rollable>

<Foldable>

Micro-LED





u-LED u-LED u-LED • • •

Si, GaN,
Sapphire Template

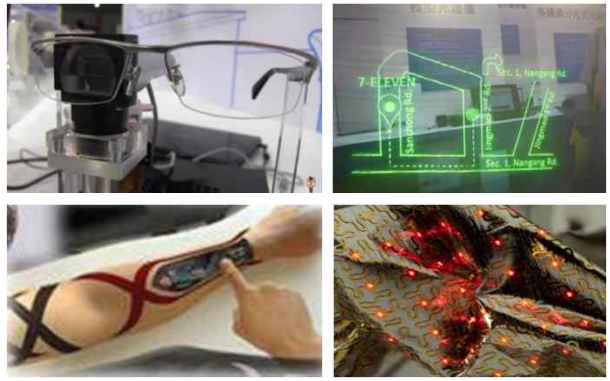
RGB Pixel, Interconnect, Integration Tech.

Transparent, Flexible, Stretchable, TFT B/P)

u-LED u-LED u-LED • • •

Si, GaN,
Sapphire Template

< Transparent / Stretchable >



< Public Display >

µLED Display II

Inorganic nature, High efficiency, Narrow Bands

Advantages

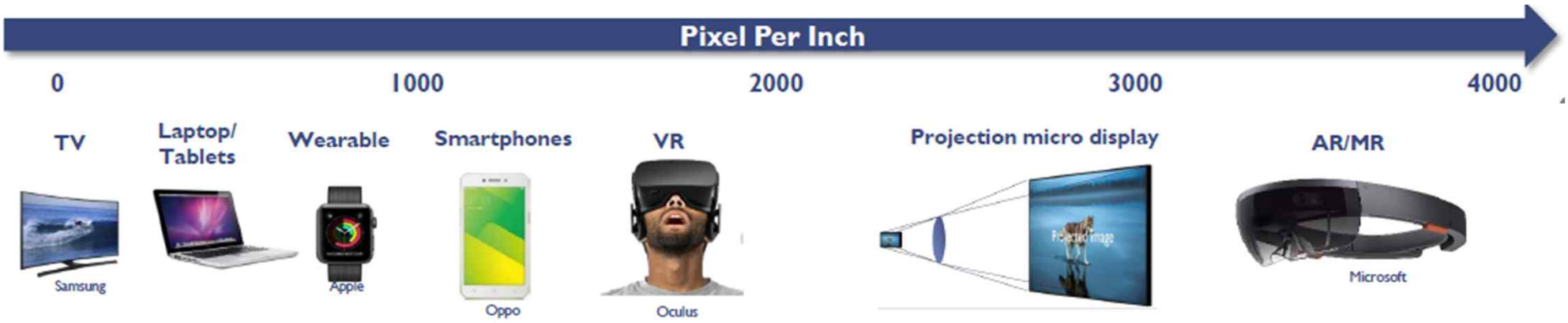
- Low energy consumption, Color gamut, Brightness, Contrast(High Dynamic Range), Fast response rates, High viewing angles,
- Long life time, environmental stability(not sensitive to air, moisture…)
- Compatibility with flexible backplane technologies to enable curved or flexible displays.

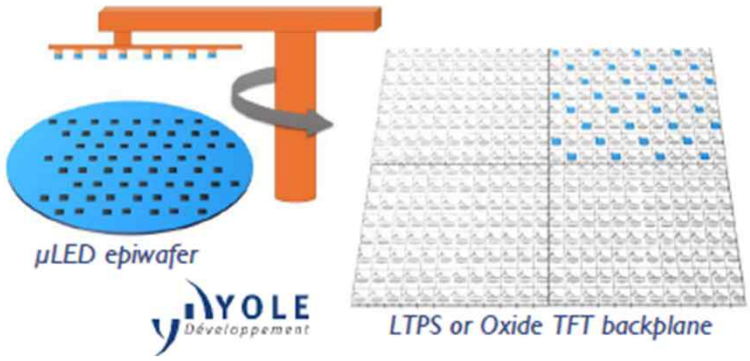
	LCD	OLED	microLEDs
Energy consumption	Medium	Medium	Very Low
Pixel density	Up to 1000 PPI (Current commercial: 500)	2500 PPI demonstrated (MicroDisplays)	Up to 5000 PPI
Brightness	< 2000 Cd/m²	<1000 Cd/m²	Up to 1E6 Cd/m2
Contrast	Low to medium	High	High
Lifetime	Good	Medium	Best
Environmental stability	Good	Medium (with appropriate encapsulation)	Best
Refresh Rates	Low (ms)	High (µs)	Very high (ns)
Viewing angles	Low	High	High
Flexibility	Low	High	Medium
Maturity	High	Medium	Low
Cost	Low	Medium	High

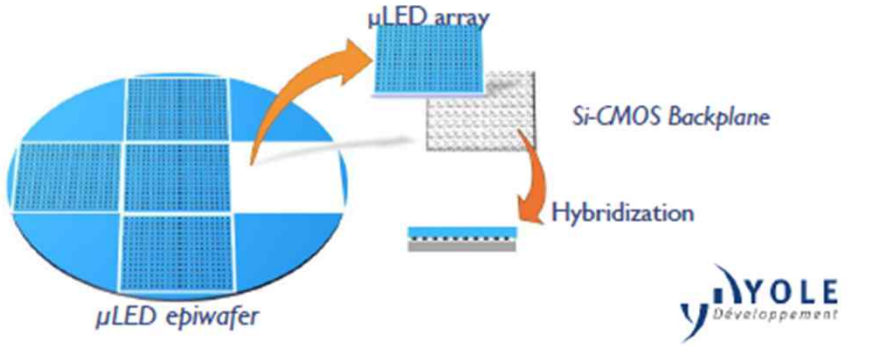
µLED Display III

Micro LED applications for the pixel density

- **Pixel Density**
  - Less than 200 ppi → Video Display, TV, Desk-Top (System Installation Business)
  - More than 400 ppi → Smart Watch, Smart Glass, AR/VR, MR, Micro Projector







Source : Yole Development 2017 Micro LED Displays

Chip Fabrication & Transfer Printing I

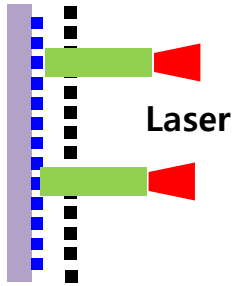
µLED process is associated with Transfer Printing method

Present : Sapphire Substrate

Future : Si Substrate

	Present	Future
Structure	Lateral/Vertical/Flip-Chip	Vertical/Flip-Chip
Wafer Size	4 inch	Over 8 inch
Lift Off	LLO (Blue/Green)	CLO (Blue/Green/Red)
TFT B/P Interconnect	Selective Printing Wafer Bonding	Monolithic Array Group Transfer Printing

< LLO >



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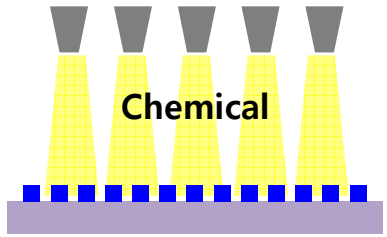

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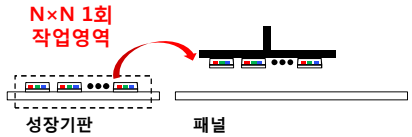
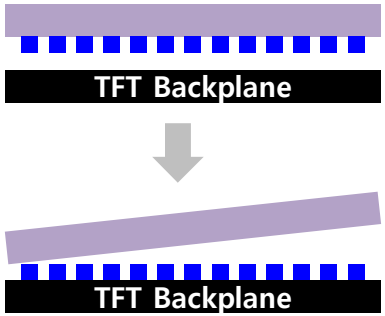
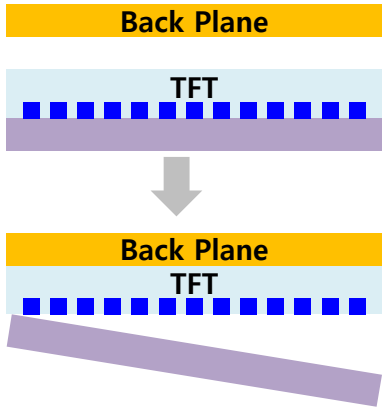


< Wafer Bonding or Array Group Transfer Printing >



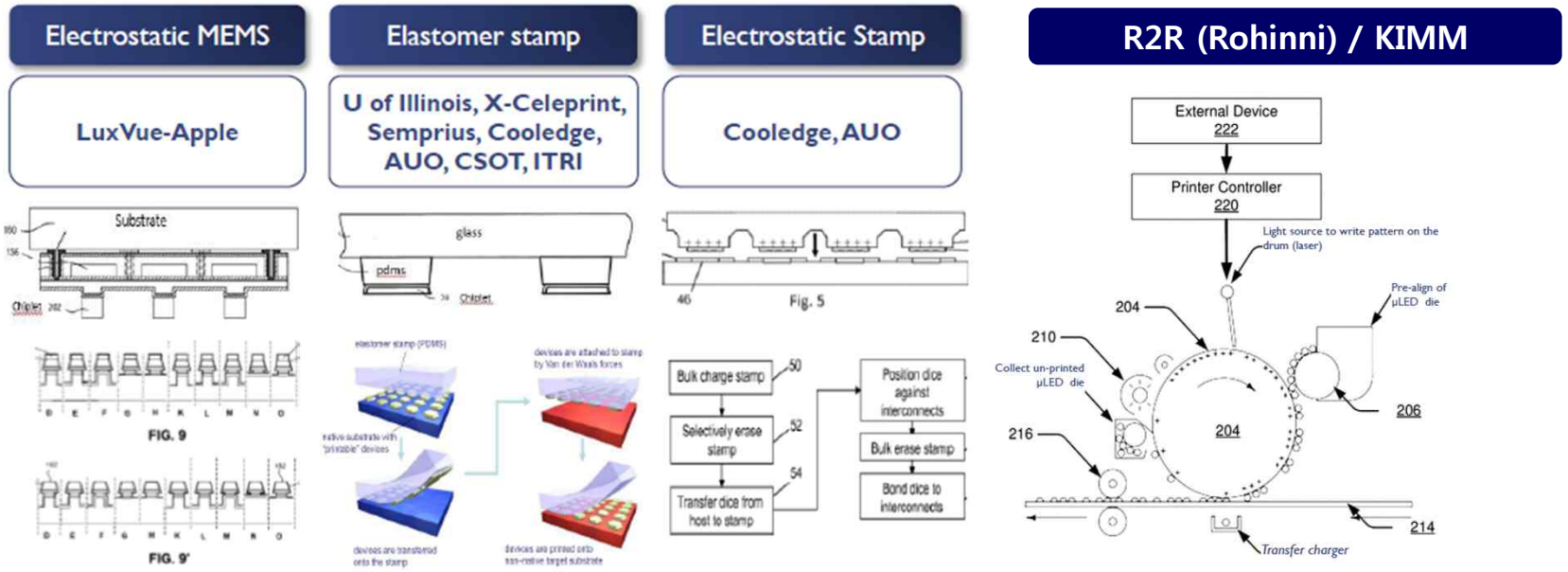
<Monolithic Integration & Array Group Transfer Printing>



Chip Fabrication & Transfer Printing II

Massively Selective Transfer Printing Method

- **Stamp Methodologies for Inducement of Adhesive Strength**
  - MEMS Head : Input Electrical Power → Electrostatic Force
  - Glue Head : Supply Heat & Light & Motion (Van der Waals) → Attachment & Separation
- **R2R Methodologies for Continuous Production**
  - Direct Attachment : Classify Feeding Roll and Pressure Roll
  - Glue Film : Array the uLED on the film and rolling it, and then give pressure to film with another roll



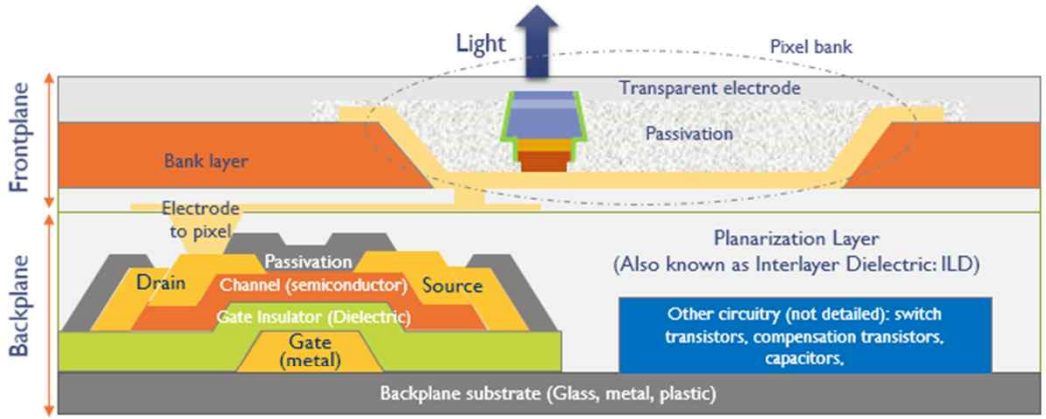
Source : Yole Development 2017 Micro LED Displays

RGB Pixelization I

AM(Active Matrix) uLED → Color uLED + TFT (CS, PS, Oxide)

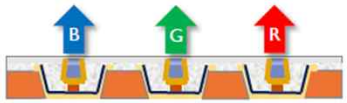
Display Pixelization of RGB Micro LEDs

- Red uLED + Green uLED + Blue uLED → Selective Transfer Printing
- Blue uLED + nano yellow phosphor + color filter → More high density, but Lower color reproducibility
- Blue uLED + Quantum Dot : Less Brightness, Higher color reproducibility



Inkjet, Deposition, Lithography

Full RGB Emitters



Red pixel	Red LED (InGaAlP)
Green Pixel	Green LED (InGaN)
Blue Pixel	Blue LED (InGaN)

Blue and Green chips + Red conversion

Red pixel	Blue LED (InGaN) + Red converter
Green Pixel	Green LED (InGaN)
Blue Pixel	Blue LED (InGaN)

Blue chip + Red and Green Conversion

Red pixel	Blue LED (InGaN) + Red converter
Green Pixel	Blue LED (InGaN) + Green converter
Blue Pixel	Blue LED (InGaN)

Source : Yole Development 2017 Micro LED Displays

Active Driving II

전류구동 (Passive) → Static / Dynamic (Duty 1/2 … 1/16)

고해상도, 역동적 영상 변환 문제 → 전류제어 한계

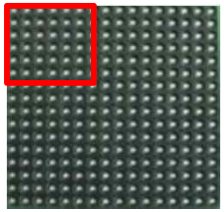
고화질, 고해상도 대응 불가 !!

Static

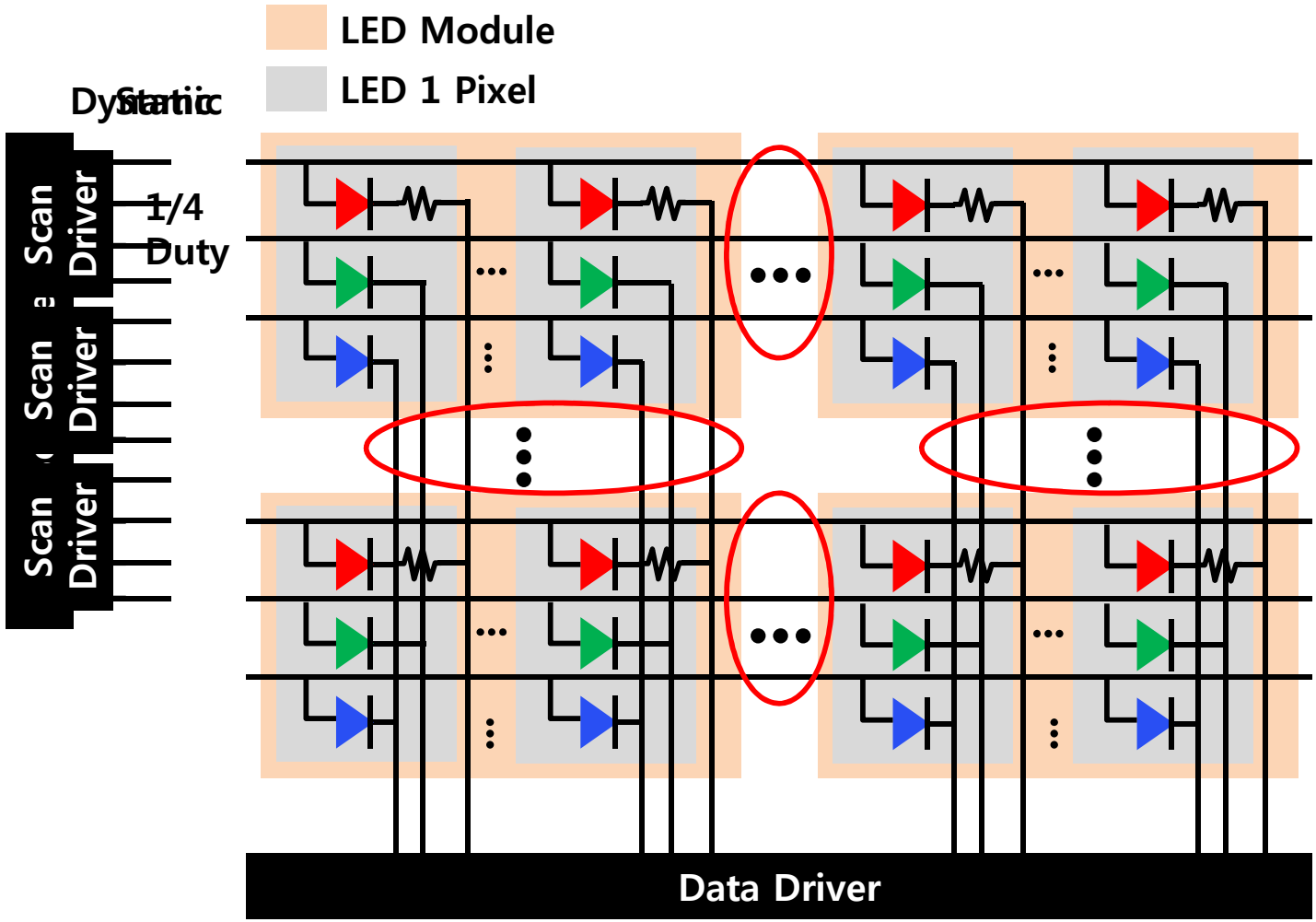
→ 고휘도, No Flicker

Dynamic

→ 저전력, Cost 절감



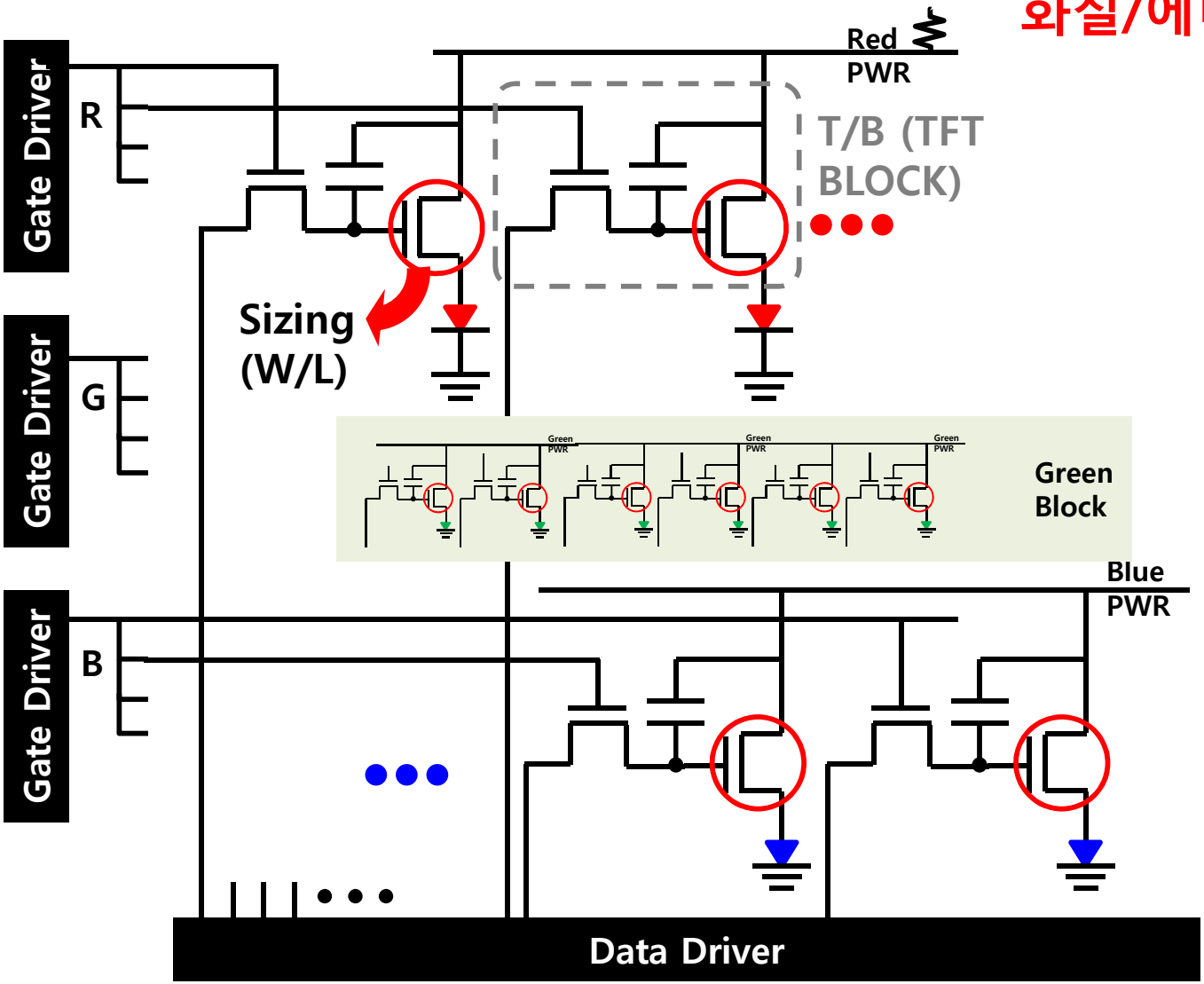
복잡합 전규구동 Driver 등

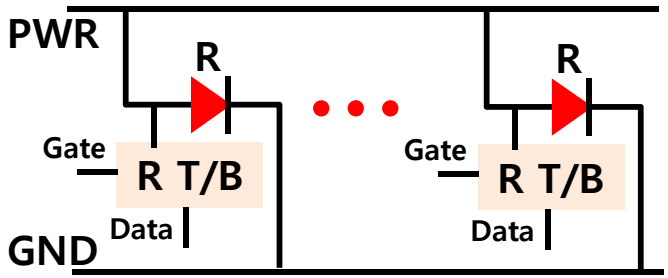


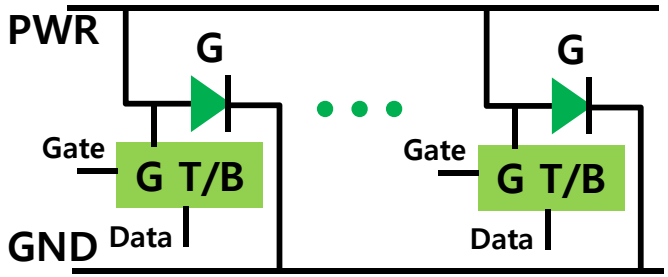
Active Driving III

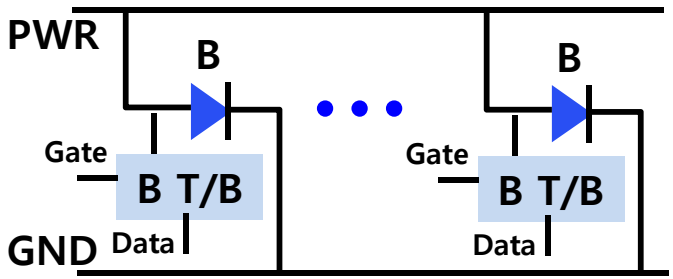
전압구동 (LCD, OLED)→ Active 구동 (Static 장점 + Dynamic 장점)

화질/에너지 절감 2배 이상 증가 !!







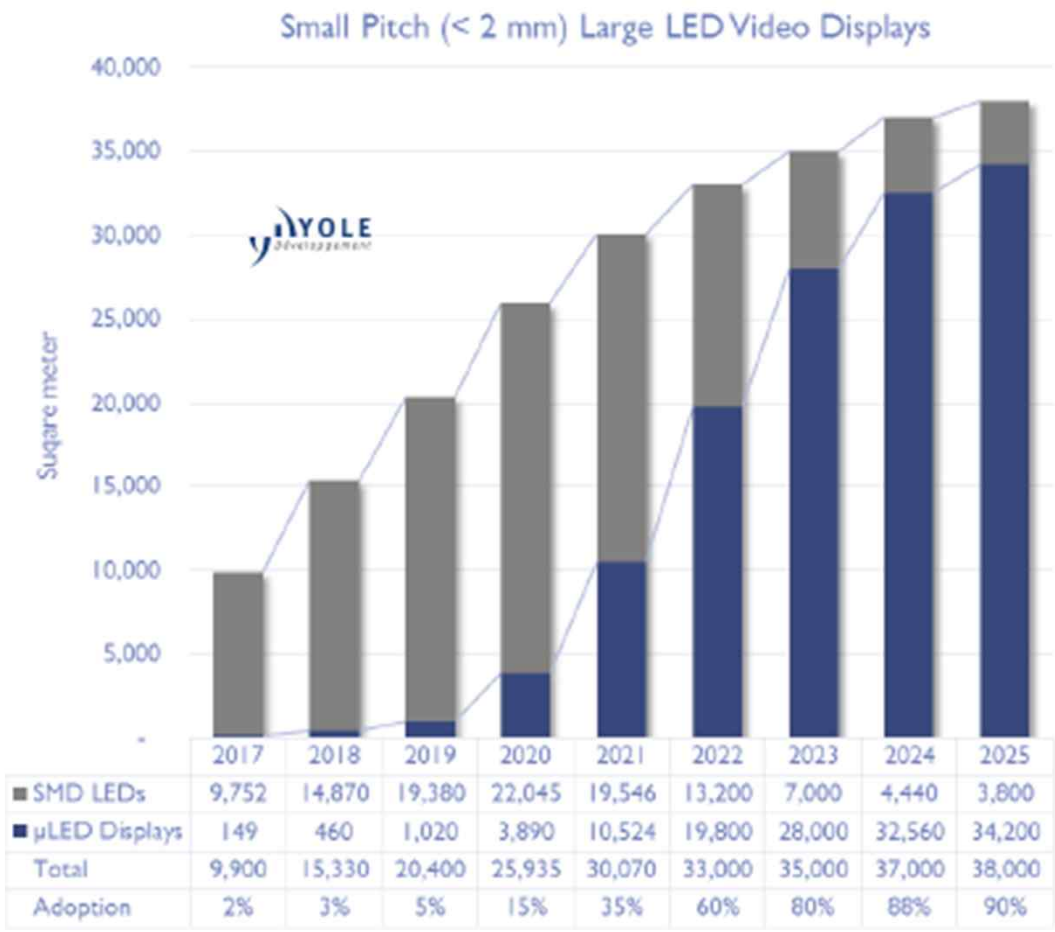


Large Display I

LED Video Display Pitch (Low 25 mm → High 0.5 mm)

- **Adoption of high resolution displays with small pixel pitch resolution**
  - **New opportunity : replacement market**
  - **New market**
    - ➢ Cinema, Traffic Control Center, Hospital, Entertainment, Game, Perfomances
  - **In 2025, 90% market share(34,200 m²)**

< Sony CLEDIS >



	2017	2018	2019	2020	2021	2022	2023	2024	2025
SMD LEDs	9,752	14,870	19,380	22,045	19,546	13,200	7,000	4,440	3,800
µLED Displays	149	460	1,020	3,890	10,524	19,800	28,000	32,560	34,200
Total	9,900	15,330	20,400	25,935	30,070	33,000	35,000	37,000	38,000
Adoption	2%	3%	5%	15%	35%	60%	80%	88%	90%

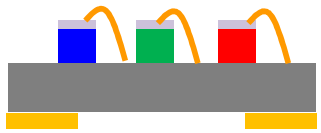
Large Display II

Wired Mini-LED → Flip-Chip M-LED → µLED : FUD → UHD → SUHD

Lower thickness & Smaller size

- Assembled PKG on the panel can give a low display quality as the pixel density is higher because of blurring effect
- Concavoconvex (凹凸) shape on the backplane bring about the diffused reflection between top glass and backplane → Require thin flip-chip and µ-PKG

Flip-Chip → PKG

	Wire	Flip-Chip (With Sapphire Sub.)	Flip-Chip (Without Sapphire Sub.)
			
Resolution	20 PPI	40 PPI	> 40 PPI
Size	0.6 mm	0.5 mm	< 0.5 mm
Thickness	0.8 mm	0.35 mm	0.2 mm

Flip-Chip → COB

- Not easy to rework
- Yield Issue
- Difficult trouble shooting for dead pixel

Flip-Chip (With Sapphire Sub.)	Flip-Chip (Without Sapphire Sub.)
	
Backplane	Backplane

Small- and Medium Display I

Big Market : Small- and Medium-Sized Display

- **Micro Display**
  - Very small (less than 1cm) in size and easy to mass-produce comparatively and do not require high maturity level of the technology (near-to-eye applications)
- **Small- and Medium-Sized Display**
  - Most challenging task is to mass-produce for applications such as smartwatches, smartphones, tablets, and TVs
- **Large-Scale Display**
  - Low pixel density, but the pixel volume required is very high in these displays, which increases the cost of the product

Display Panel Size	2017	2019	2020	2021	2022	2023	2025	CAGR
Small- and Medium-Sized Display	-	157.5	169.3	2,149.6	5,483.7	13,292.0	15,929.6	115.9%
Microdisplay	-	673.9	788.5	1,115.1	1,311.5	1,763.7	2,782.4	26.7%
Large-Scale Display	253.3	580.6	636.9	655.7	690.0	740.7	866.2	16.6%
Total	253.3	1,412.1	1,594.7	3,920.4	7,485.3	15,796.5	19,578.2	55.0%

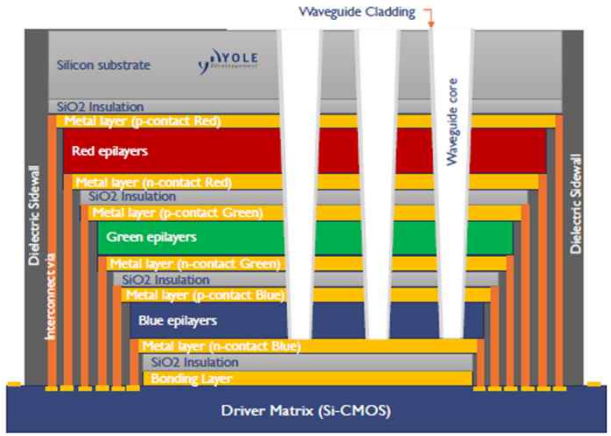
Source : Secondary Literature, Expert Interviews, and MarketsandMarkets Analysis 2017

Small- and Medium Display I

Wafer Bonding (Hybridization) & Monolithic Integration

- **Monolithic Integration (TFT) → Group Array Bonding**
  - The deposition the LED array on a CMOS or TFT matrix is not practical due to the temperature of MOCVD above 1000 ℃
  - Various companies have suggested the use of GaN based TR same wafer as the LED array
  - Players : Osram, Nth Degree, Lumiode, eMargin
- **Wafer or Group Array Transfer & Bonding (Hybridization)**
  - The several hundred thousand µLEDs and the transistor matrix are manufactured separately using the appropriate technologies, and then assembled together
  - Players : LETI, Aledia, mLED, HKUST, III-V, ITRI, Osram, NAMI, Ostendo, Lumens

< Ostendo >



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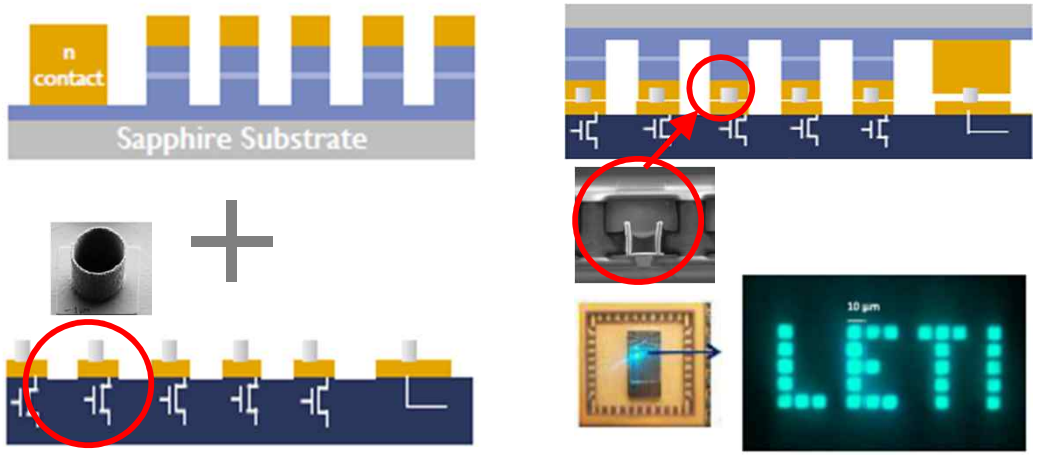


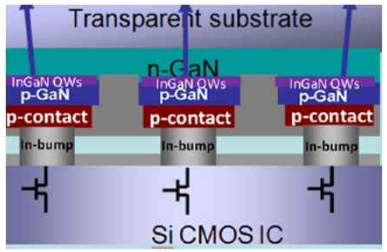
Source : Yole Development 2017 Micro LED Displays

Small- and Medium Display I

Wafer Bonding (Hybridization) & Monolithic Integration

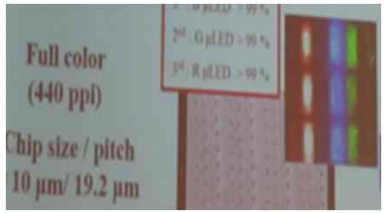
Monolithic Integration & Wafer bonding Players

Texas Tech. Univ.



Green (1 uA)
→ 120 x 160 pixels
→ 12 um Pixel

ITRI

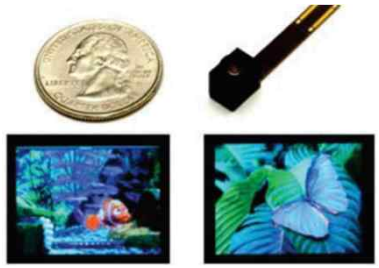


Full Color 440 ppi @ 0.55”
→ 427x240 array (500 nit)
→ 10 um Pixel

ITRI

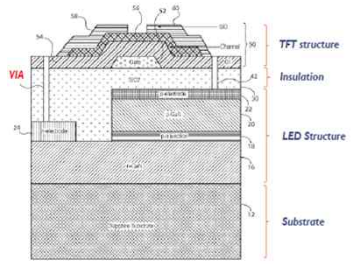
Green @0.37” (1500nit)
→ 427x240 array
→ 10 ~ 20 um pixel

Ostendo



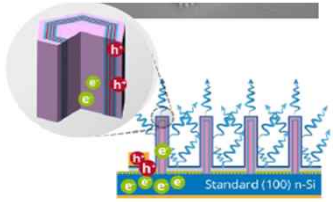
Full Color 5000 ppi
→ 1280x720 array
→ 5 um Pixel

eMagin



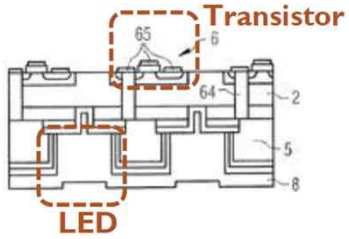
Monolithic Integration
→ Oxide TFT

Aledia

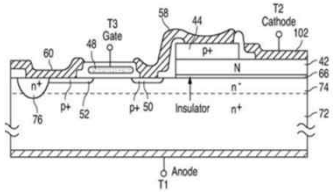


3D Micro/Nano LED
→ GaN on Si

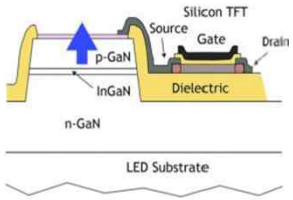
OSRAM



Nth Degree



Lumiode



Source : Yole Development 2017 Micro LED Displays, LED Forum 2016(Taiwan)

Conclusion

- Present very small market, but important potential market
- Core technology is transfer printing, but must not ignore the conventional technologies to commercialize for appropriate applications (Front- and Back-end)
- At first, micro display market with low pixel density is supposed be opened
- Smart phone and smart watch business will be driving force for the growth of the total market
- Active matrix technology in the field of large scale display can accelerate the enlargement of area in line with government policies
- Because of the needs of high brightness for AR/MR applications, micro display using μLEDs is the greatest attractive market, but the stable monolithic structure without transfer bonding process should be developed for the mass production