June 4, 2019

Leti Photonics & MicroLED Displays Workshop

NTUH International Convention Center, Taipei, Taiwan

CHALLENGES AND SOLUTIONS FOR ADVANCED MICROLED DISPLAYS

François Templier

Strategic Marketing, Displays and Displays Systems

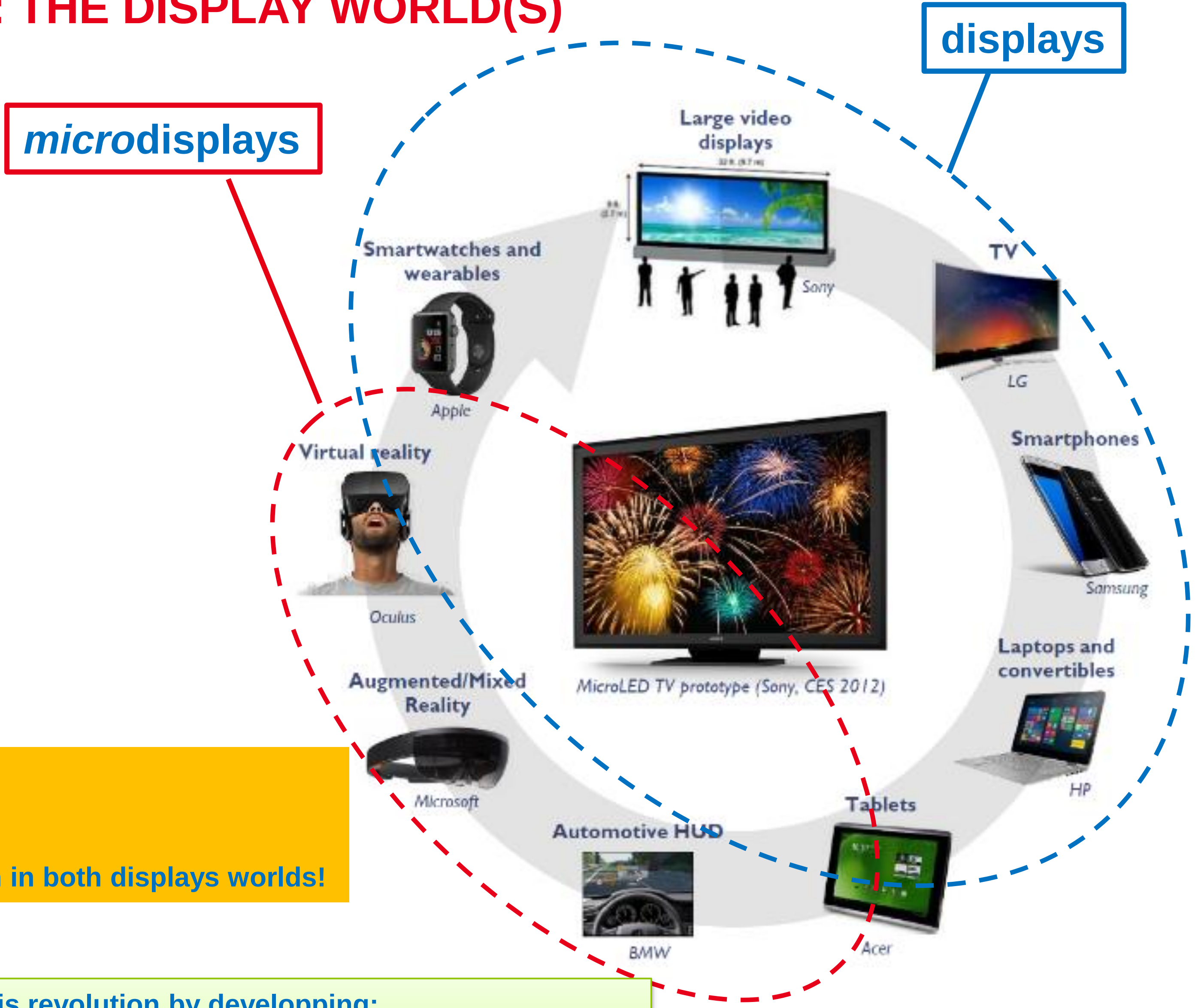
Optics and Photonics Department

CEA-LETI, Grenoble , France

CONTEXT: THE DISPLAY WORLD(S)

TODAY, the display worlds:

- Microdisplays:
    - LCD, OLED, MEMS, ..
    - CMOS technology
- Displays:
    - LCD, OLED, …
    - TFT technology



microLED technology:
- now emerging
- TOMORROW:
    → Will bring revolution in both displays worlds!

LETI intends to parcipate to this revolution by developping:
- Ultrahigh-brightness LED microdisplays for Augmented Reality applications
- Advanced solutions for large area microLED displays

OUTLINE

- Introduction
- Challenges and (some) solutions for GaN microdisplays
  - LED microdisplays fabricated with hybridization technology
    - Gen1 and Gen2 GaN microdisplay demonstrators
  - LED microdisplays fabricated with direct bonding technology
  - Other challenges for microdisplays
- Challenges and (some) solutions for MicroLED displays
  - microLED Transfer process
  - microLEd display driving
- Conclusion

INTRODUCTION: WHY GAN MICRODISPLAYS?

Head-mounted Displays
→see-through systems

Augmented reality

New applications /
New markets

New requirements:
- system
-display

System requirement:
- Compactness
- Field of view (immersion)

OLED microdisplay

emissive

1000 Cd/m²

Need more..

Microdisplay requirement:
- Image quality
- Compactness
- Low consumption
- High brightness

New display: iLED GaN microdisplay

ILED: GAN EMISSIVE MICRODISPLAYS

GaN for LED displays

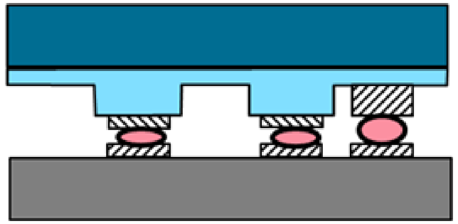
→high brightness
→Reliability: LT, T°

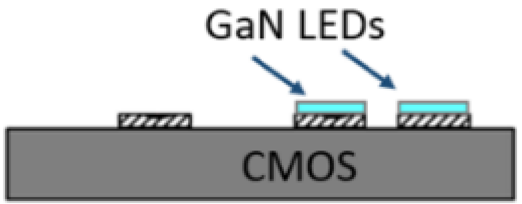
Existing approaches for GaN displays fabrication:

GaN array + active matrix?

GaN: High T°

Hybridization / 3D integration:

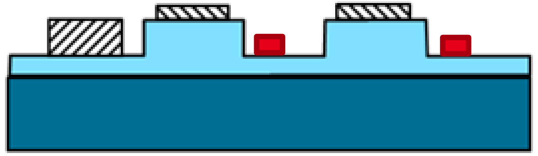




LETI:
- Hybridization
- Monolithic CMOS+ GaN

Monolithic:

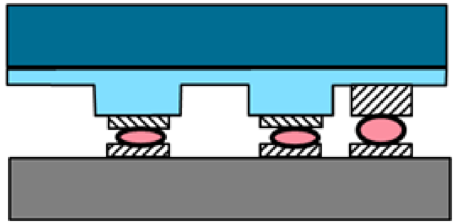
GaN +TFT



CMOS +GaN

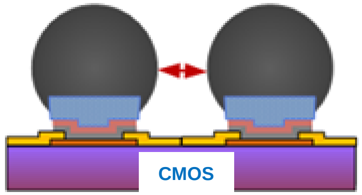
CHALLENGES FOR HYBRIDIZATION OF MICRODISPLAYS

Hybridization?



Classical hybridization technique: flip-chip In bump

Pitch limitation: 15 µm



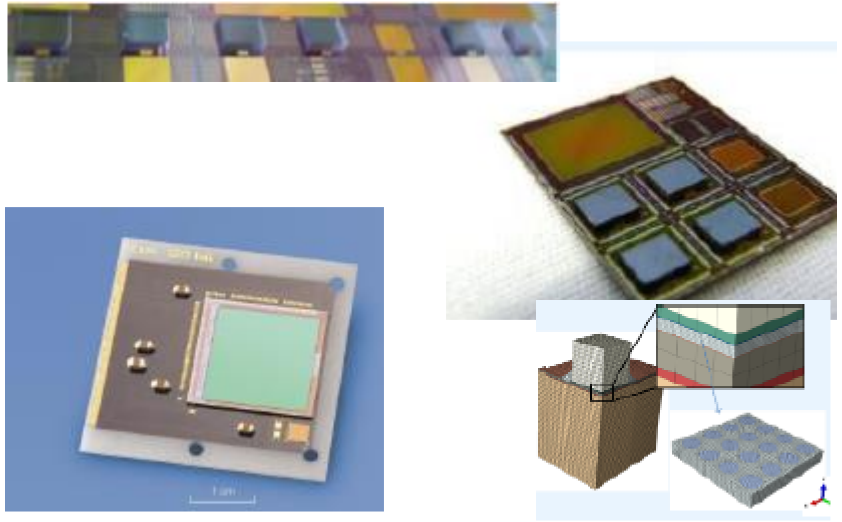
Case of microdisplays:

-10 µm, towards 5 µm

- GaN: CTE mismatch compatible

→ Other solution needed

Hybridization technologies at LETI: 3D, image sensors, …



Many hybridization technologies

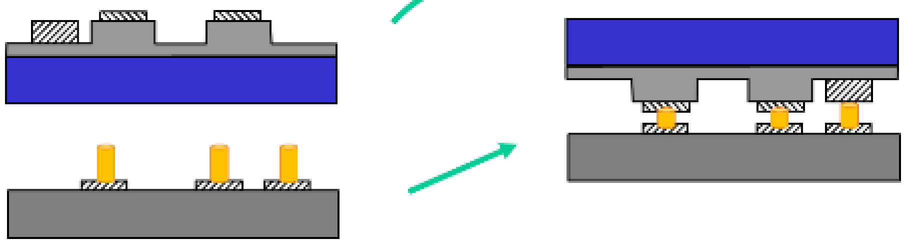
Microtube technology

LED MICRODISPLAYS FABRICATED WITH HYBRIDIZATION TECHNOLOGY

Hybridization with micro-tube technology

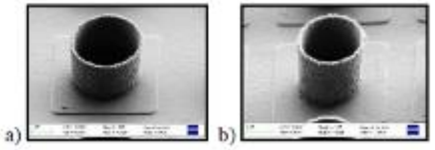
Principle: µTube inserted in pad

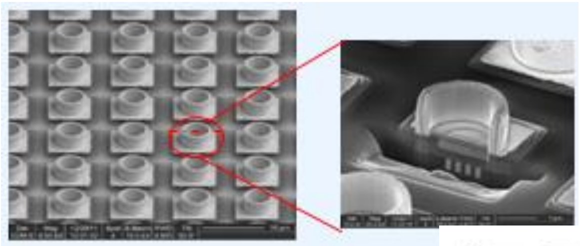
Schematic drawing of the insertion flip-chip technique

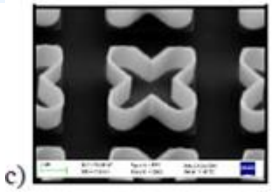


Microtubes on silicon side:

silicon side: ROC, active-matrix

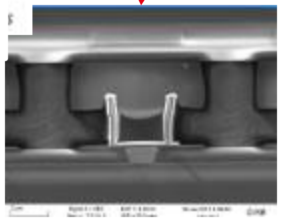


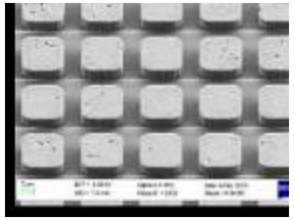




Pads on opposite side:

top side: sensor, …GaN array

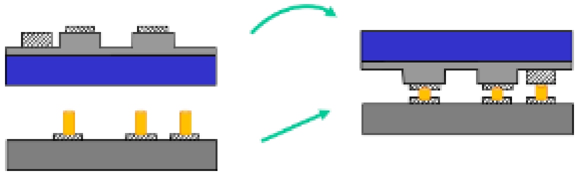




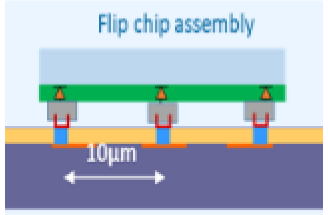
- Room temperature assembly using thermo-compression
- Few mN per connection
- Multi materials approach possible for insertion
- Standard IC technology

DISPLAY DEMONSTRATORS

2 types of display demonstrators



	Demo Gen 1	Demo Gen 2
GaN Array	10 µm pitch	10 µm pitch
Resolution	300 x 252	873 x 500 (WVGA)
Driving circuit	1-level connection Silicon circuit	Full CMOS active-matrix



Objective

Demonstrate
- 10 µm pixel pitch
- GaN potential (Power)

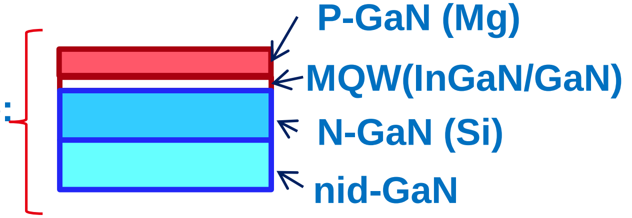
Demonstrate
- High res; small pitch (10 µm)
- Full video operation

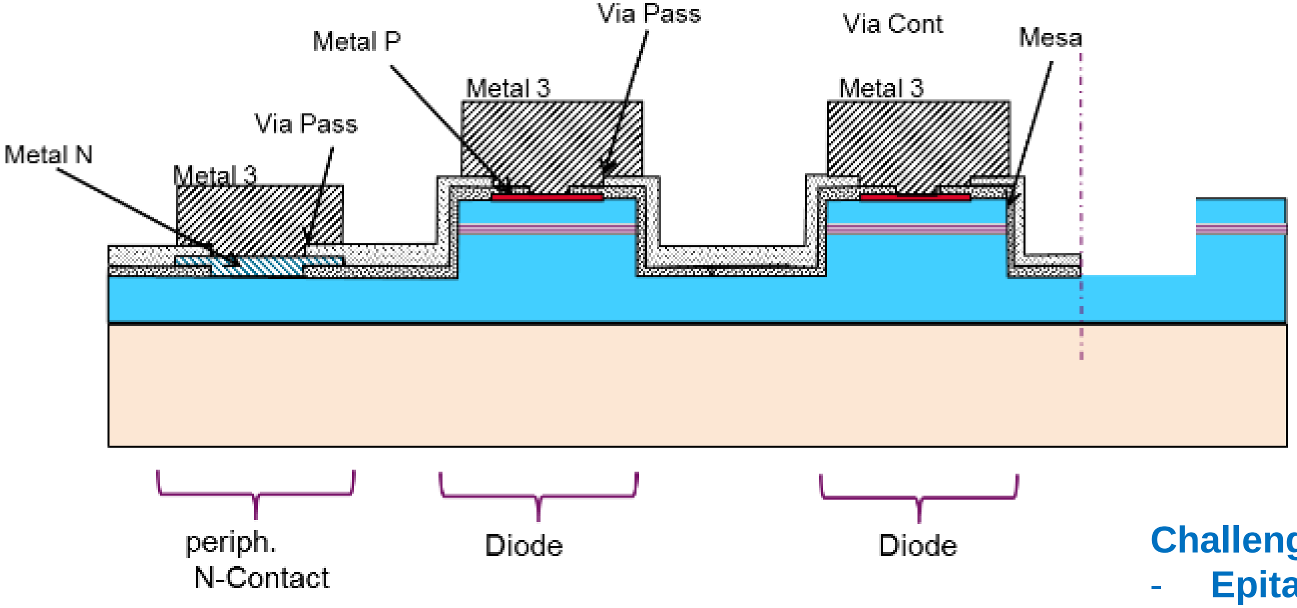
DEVELOPMENT OF 10 µM PITCH GAN LED ARRAY

GaN Diode process on saphire

→ Towards small-pitch LED arrays
→ Development of dedicated process

Epi LED structure: (MOCVD)



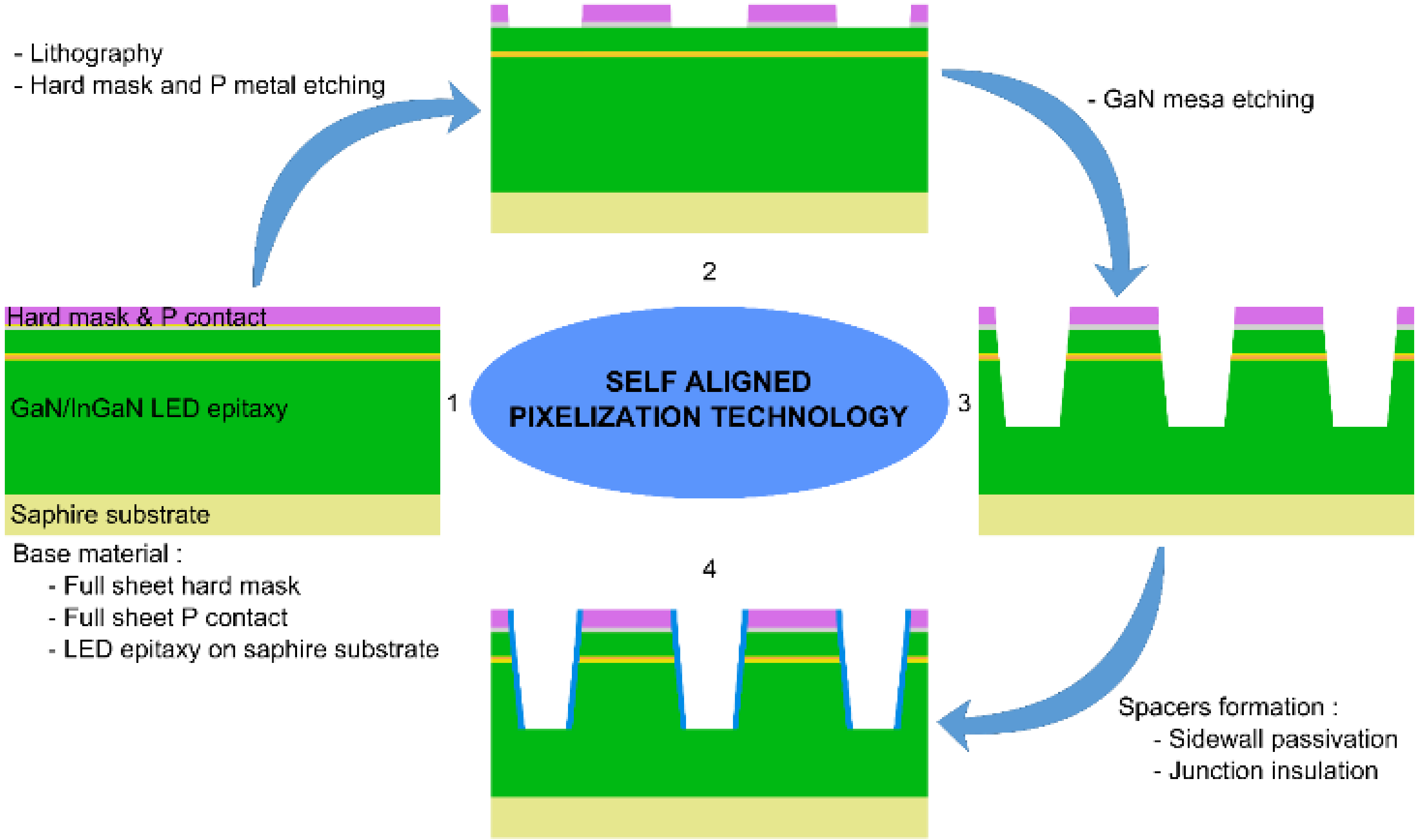


Mesa
Metals P/N
Insulations

Challenges:
- **Epitaxy quality**
- **Contacts**
- **…Small-pitch**

DEVELOPMENT OF 10 µM PITCH GAN LED ARRAY

- Self aligned technology

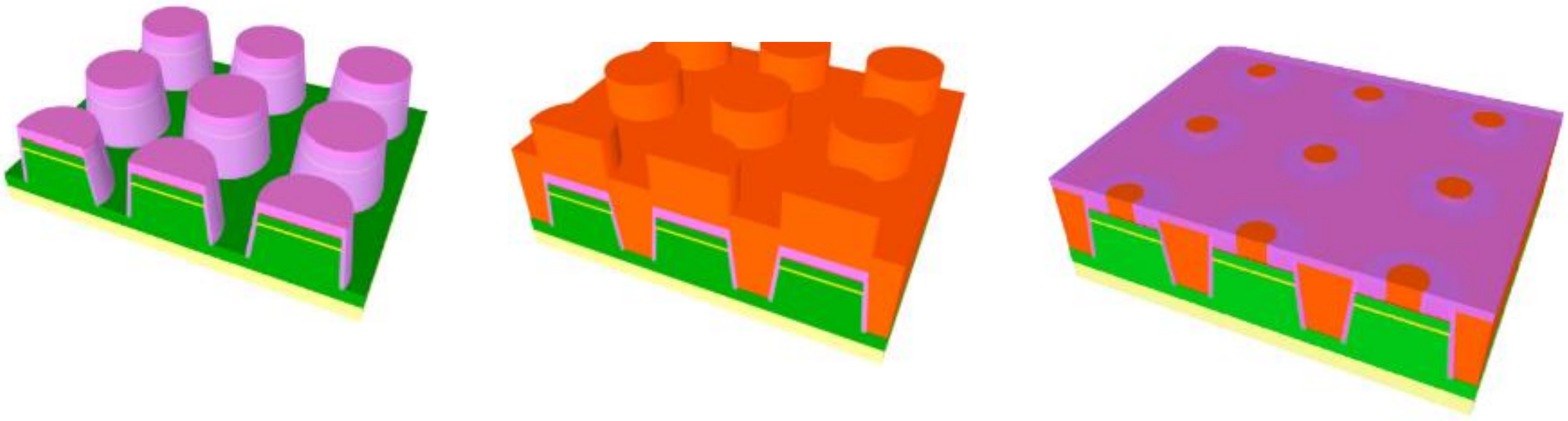


L Dupré et al, « ***Processing and characterization of high resolution GaN/InGaN LED arrays at 10 micron pitch for micro display applications”***, Photonics WEST 2017 – SPIE OPTO 2 Feb 2017

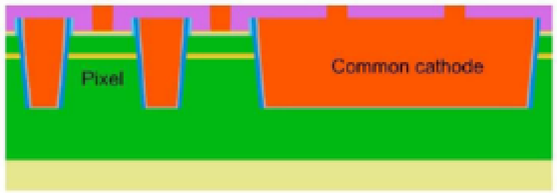
LED MICRODISPLAYS FABRICATED WITH HYBRIDIZATION TECHNOLOGY

10-µm pitch microLED array fabrication:

GaN LED array: 4-in. sapphire substrates.



- **Damascene**
- **Self-aligned**
- **Common cathode with metal grid**

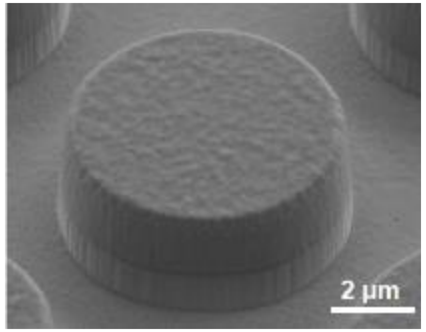


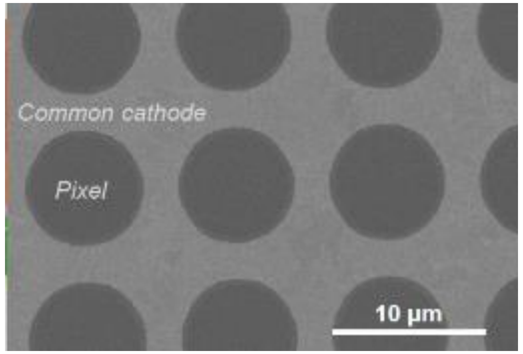
→ ***10 µm pitch***
→ ***High performance***

LED MICRODISPLAYS FABRICATED WITH HYBRIDIZATION TECHNOLOGY

10-µm pitch microLED array fabrication:

GaN LED array were fabricated on 2-in. and 4-in. sapphire substrates.





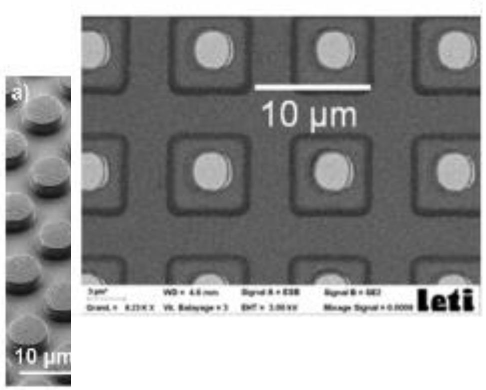
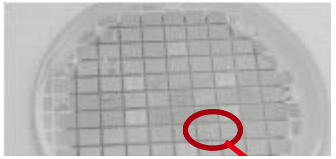
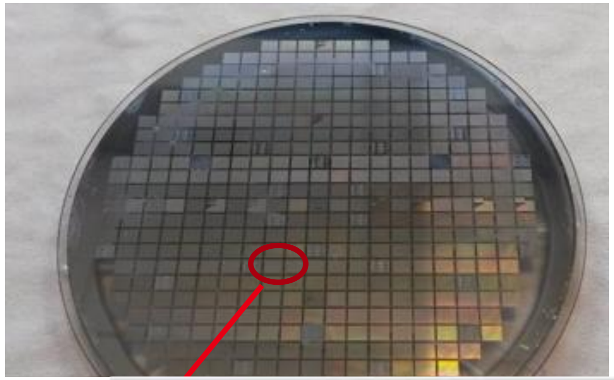
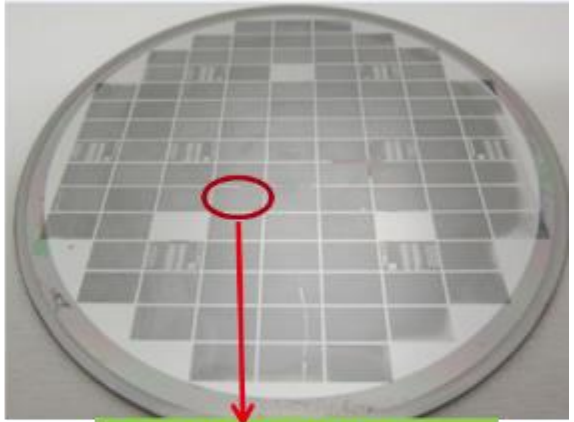


Figure 3. SEM images of 8 µm pixels at a pixel pitch of 10 µm after spacers formation. (a) The GaN mesa is 1 µm deep, inset is a zoom on a single µLED (b) The GaN mesa is etched down to the sapphire substrate, inset is a cross sectional view of a pixel revealing the internal structure.







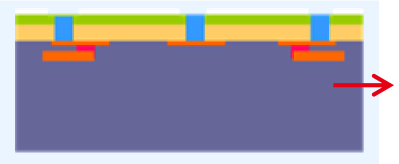
Each die: GaN array :
873 x 500 = 436 500 pixels
at 10 µm pitch

L Dupré et al, « *Processing and characterization of high resolution GaN/InGaN LED arrays at 10 micron pitch for micro display applications”*, Photonics WEST 2017 – SPIE OPTO 2 Feb 2017

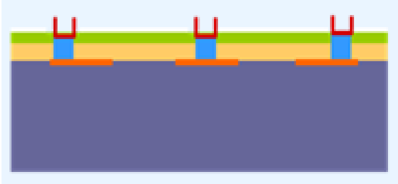
HYBRIDIZATION OF 10 µM PITCH GAN LED ARRAY
DEMO GEN 1

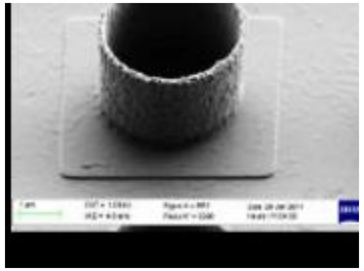
Fabrication of silicon interconnect

- patterning an interconnect network,
- patterning metal pads,
- depositing microtubes on the pads



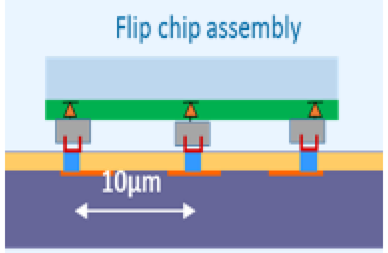
Demo 1

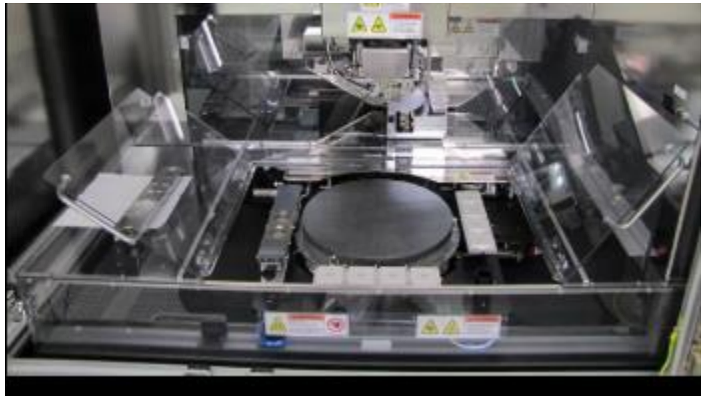




Hybridization of display device

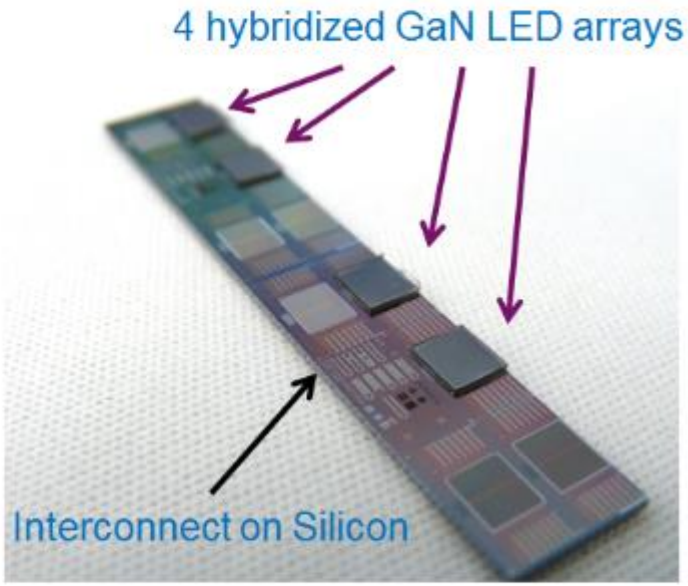
Die (GaN) to wafer process





SET FC300
+ microenvironment →limit the particulate contamination on the wafer during the chip-to wafer bonding.

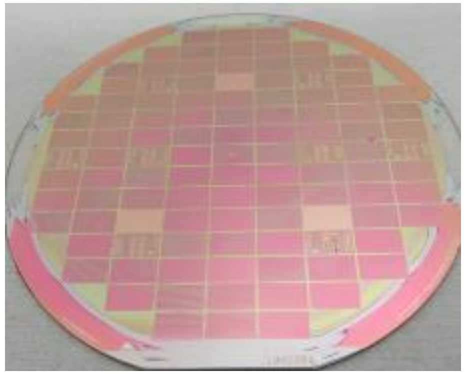
GaN arrays hybridized on Si at a pixel-pitch of 10 µm



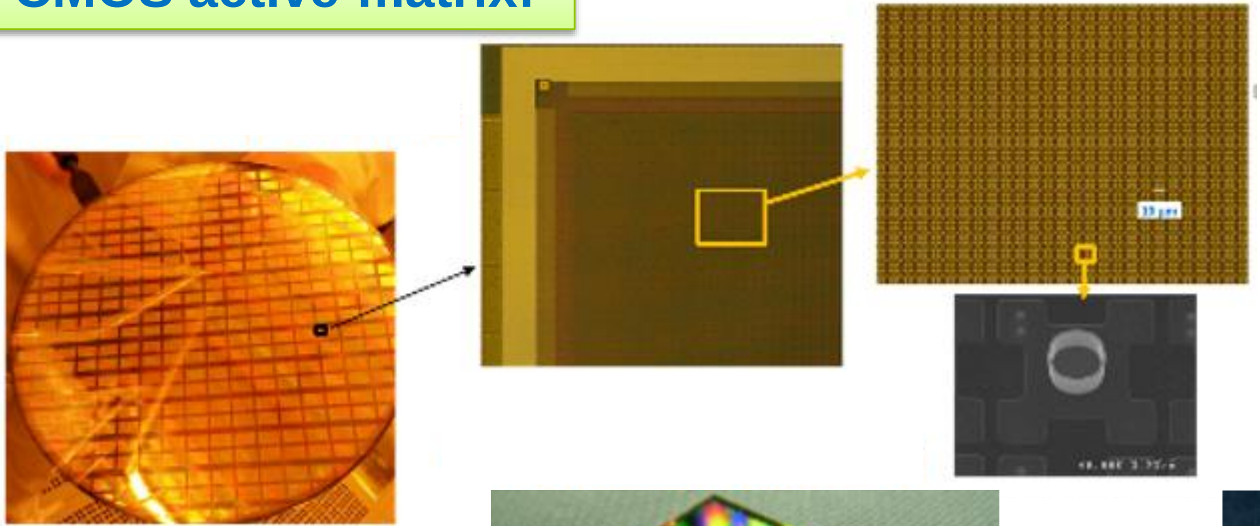
DEMO GEN 2: ACTIVE-MATRIX GAN LED MICRODISPLAY

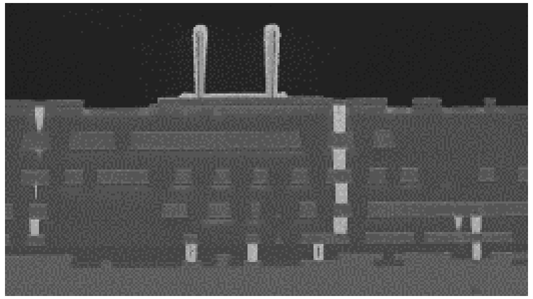
- **GaN array:**

873 x 500 pixels
10 µm pitch

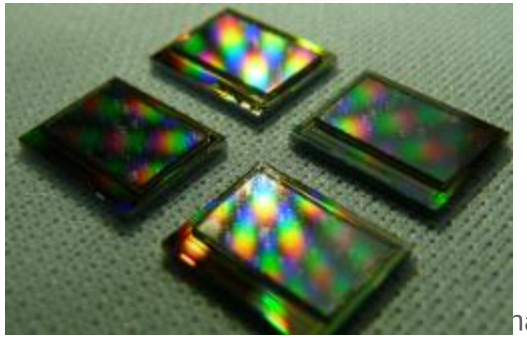


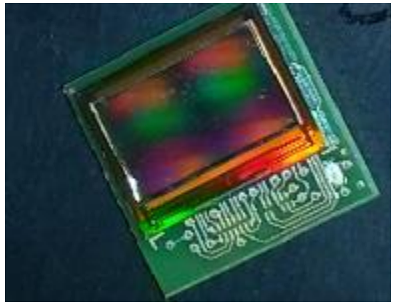
- **CMOS active-matrix:**



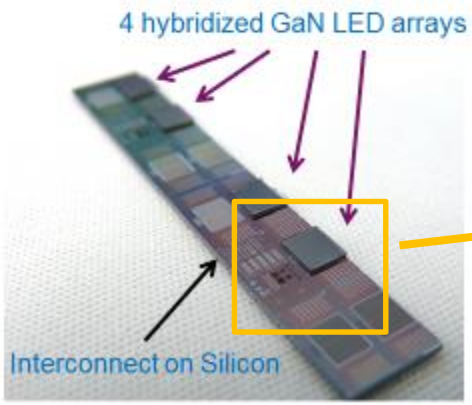


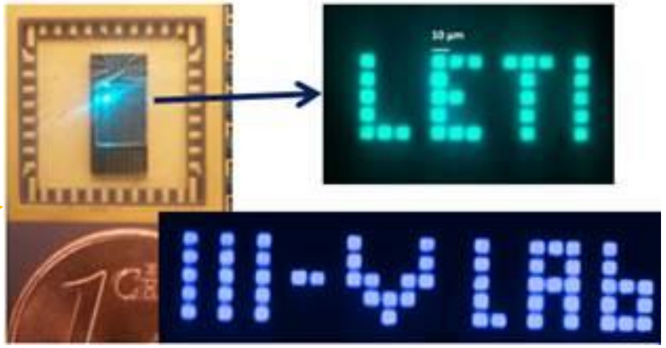
- **Hybridization:**





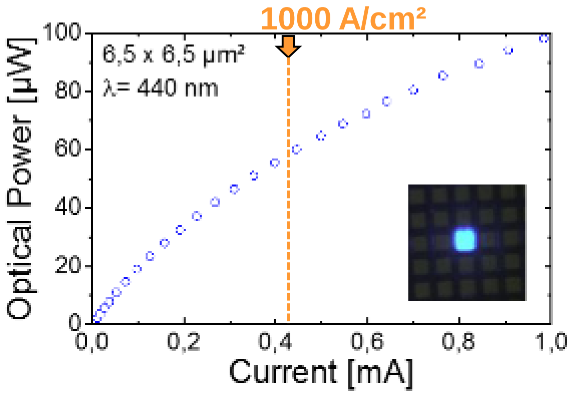
DEMO GEN 1: CHARACTERIZATION



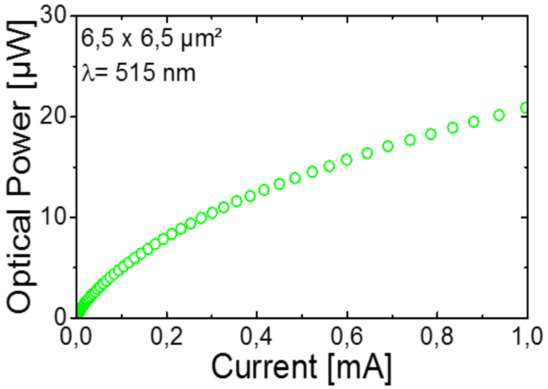


Optical power

Blue LEDS:



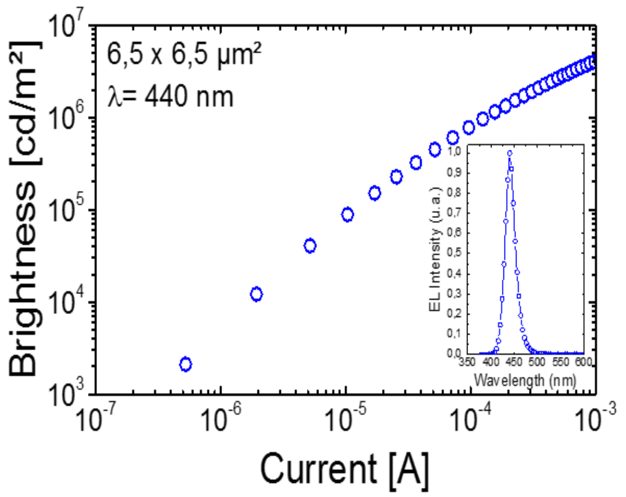
Green LEDS:



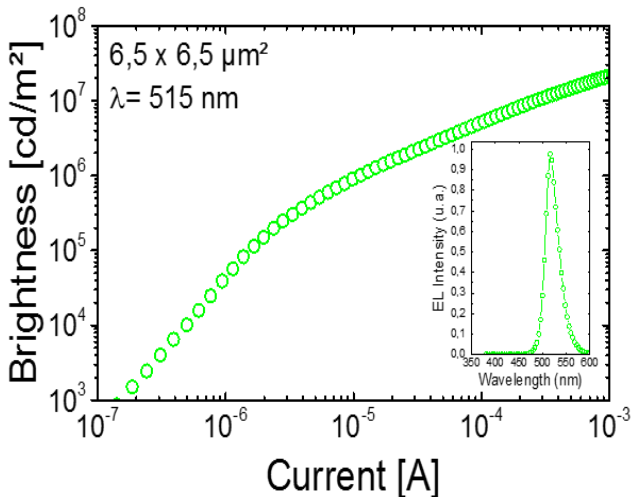
DEMO GEN 1: CHARACTERIZATION

Brightness

Blue LEDS:



Green LEDS:



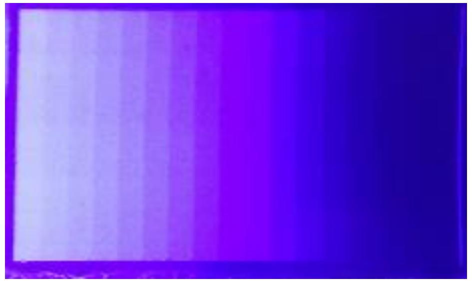
	Wavelength (nm)	Brightness (Cd/m²)		max EQE (%)	max WPE W/W (%)
		at 10 µA	at 1 mA		
Blue Pixel	**440**	**~ 10^5**	**~ 4 x 10^6**	**9.5**	**7,8**
Geen Pixel	**515**	**~ 10^6**	**~ 2 x 10^7**	**5.9**	**3.4**

LED MICRODISPLAYS FABRICATED WITH HYBRIDIZATION TECHNOLOGY

Active-matrix WVGA (873 x 500) LED demonstrators

Monochrome Blue

« Motion GaN Blue »
active-matrix WVGA
10 µm pixel pitch



Monochrome Green

« Motion GaN Green »
active-matrix WVGA
10 µm pixel pitch

Full resolution…873 x 500 pixels
Video…

Brightness:
Blue: 300 Cd/m²
Green: 10 000 Cd/m²

PIXEL PITCH: A KEY CHALLENGE

Pixel-pitch in emissive microdisplays:
(subpixel)

OLED
(products)

eMagin (2012)
0.86-in.
1920x1200
4.8 µm

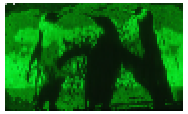
Microoled (2012)
0.61-in.
1300x1044
4.7 µm

Sony (2014)
0.23-in.
640x400
3.9 µm

Microoled (2014)
MDP03 0.39-in.
1024x768
3.8 µm

iLED (GaN)
(prototypes)

Texas Tech (2011)
0.31-in
640x480
15 µm



Ostendo (2014)
0.29-in.
640x360
10 µm

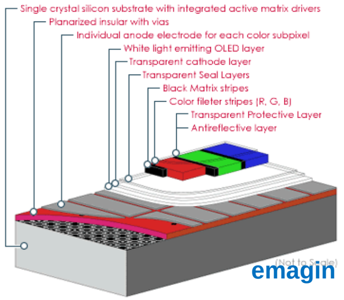
Leti / 35 Lab (2017)
0.38-in
874x500
10 µm

→ ***Big gap!***
→ ***To be filled!***

Why such gap?

Fabrication approaches:

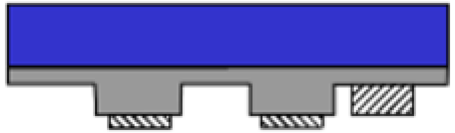
OLED:



→ **monolithic, full CMOS**

iLED:

→ **Separate fabrication**



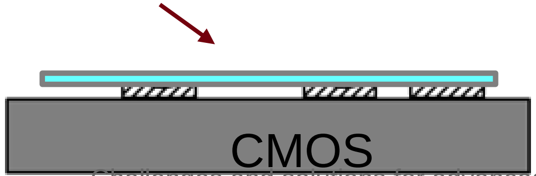
→ ***Assembly step***

→ ***Alignement***

→ **Bottleneck!**

Solution:

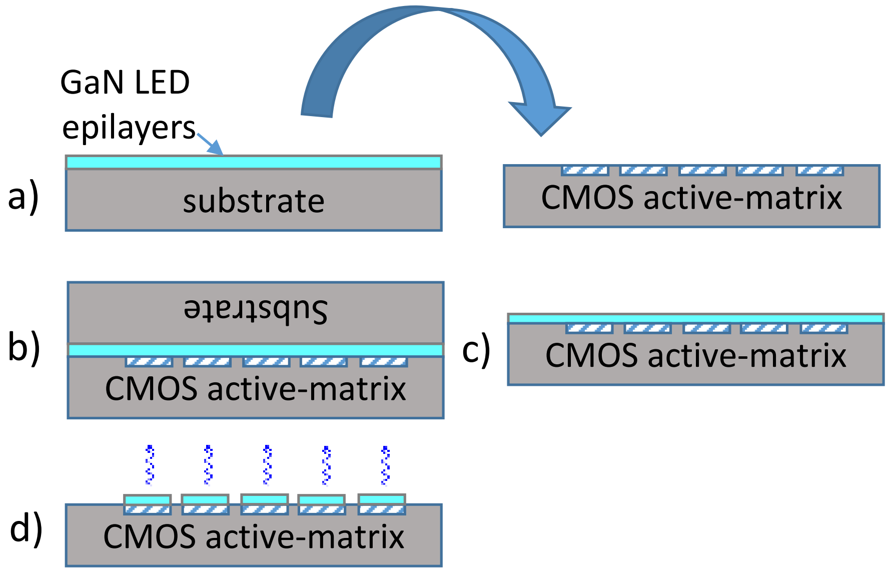
Monolithic CMOS + GaN transfer:

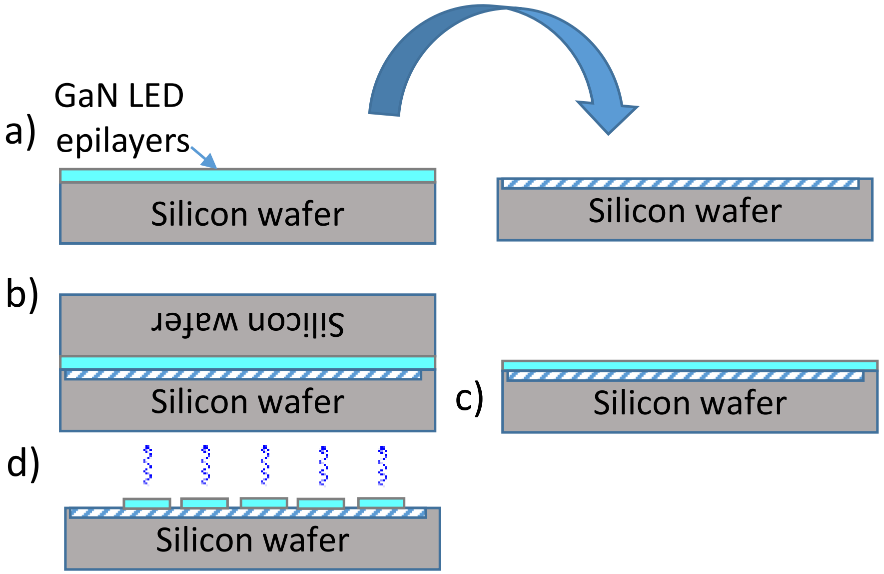


NOVEL APPROACH FOR GAN MICRODISPLAYS

Novel approach: transfer of GaN on CMOS

Proof-of-concept/ feasibility demonstration:





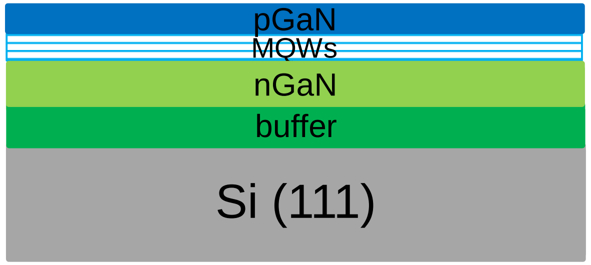
→No alignement
→Full CMOS

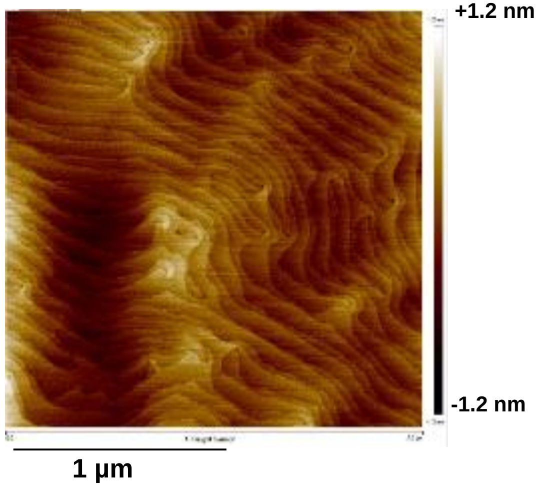
→ Integrate key steps /Led operation?
→ Small pixel pitch?

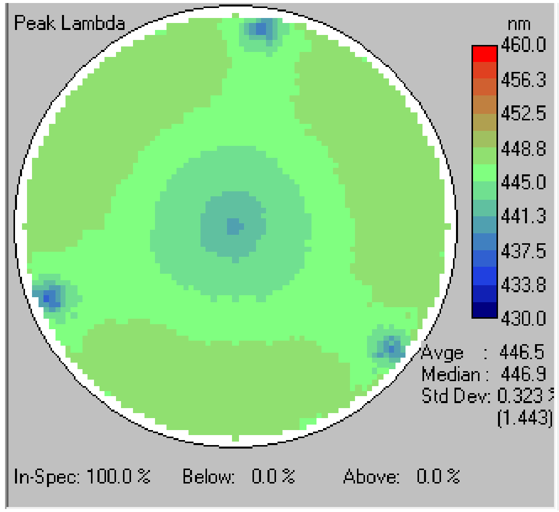
NOVEL APPROACH FOR GAN MICRODISPLAYS

Feasibility demonstration

1- LED epilayer on 200-mm Si







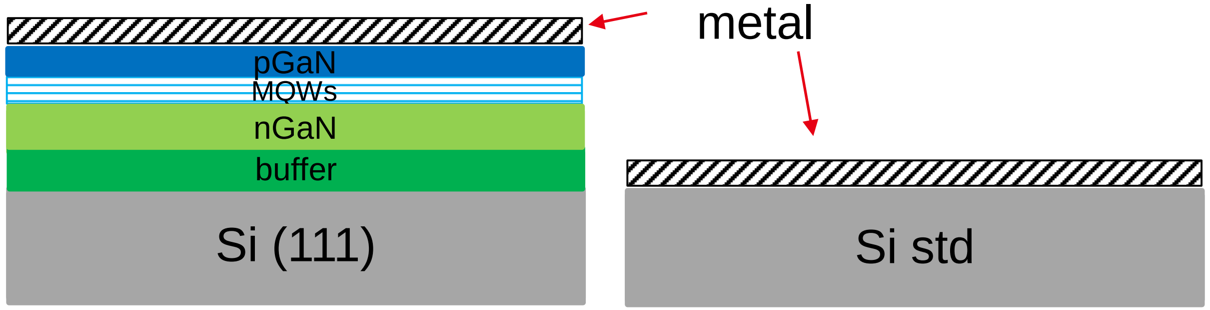
Key features:
- Bow (<50µm)
- λ homogeneity
- Surface roughness

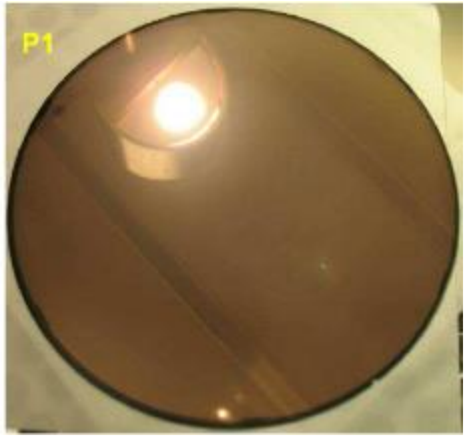
NOVEL APPROACH FOR GAN MICRODISPLAYS

Feasibility demonstration

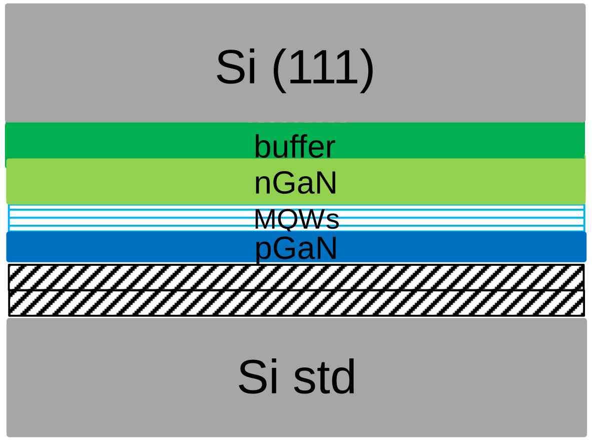
2- Direct bonding on 200-mm Si

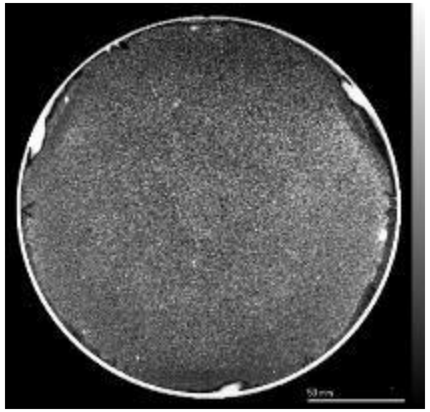
Metal deposition





Bonding



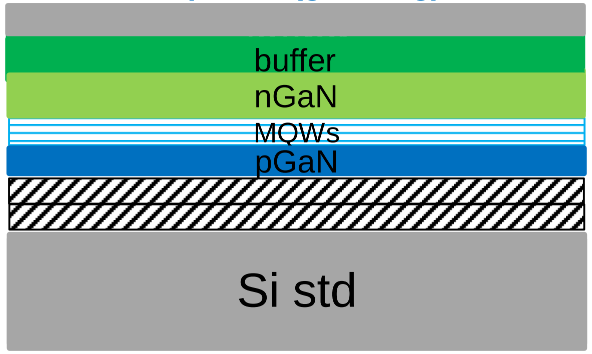


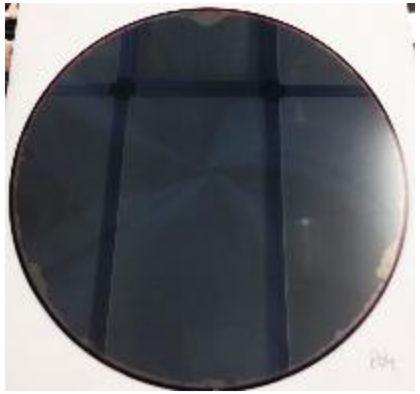
NOVEL APPROACH FOR GAN MICRODISPLAYS

Feasibility demonstration

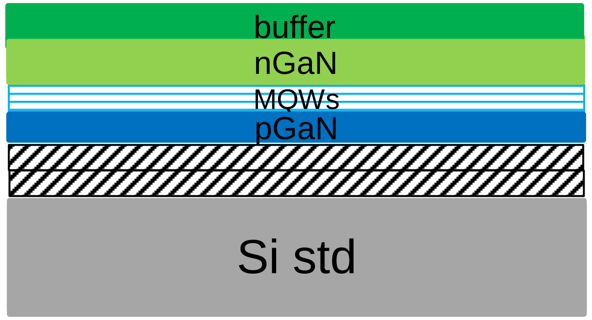
2- Direct bonding on 200-mm Si

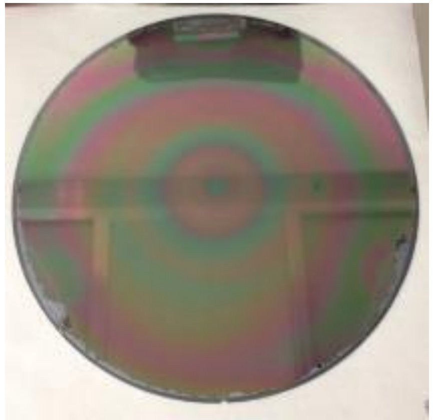
Silicon removal: partial (grinding)

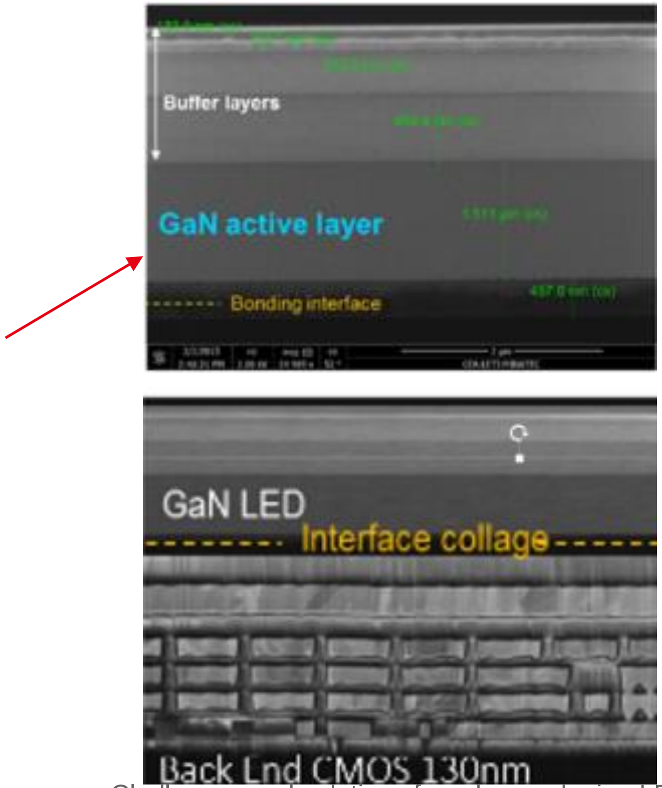




Silicon removal: full





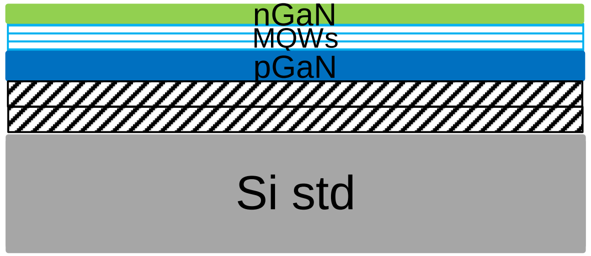


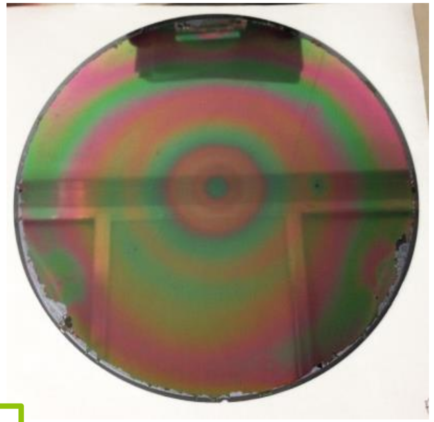
NOVEL APPROACH FOR GAN MICRODISPLAYS

Feasibility demonstration

2- Direct bonding on 200-mm Si

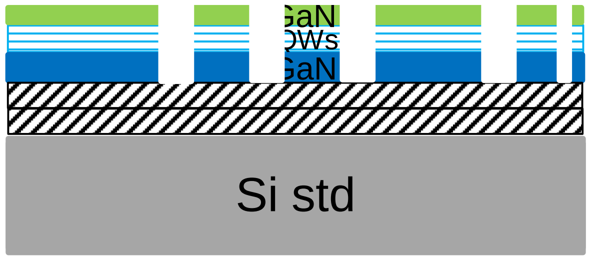
Buffer removal:stop on N+

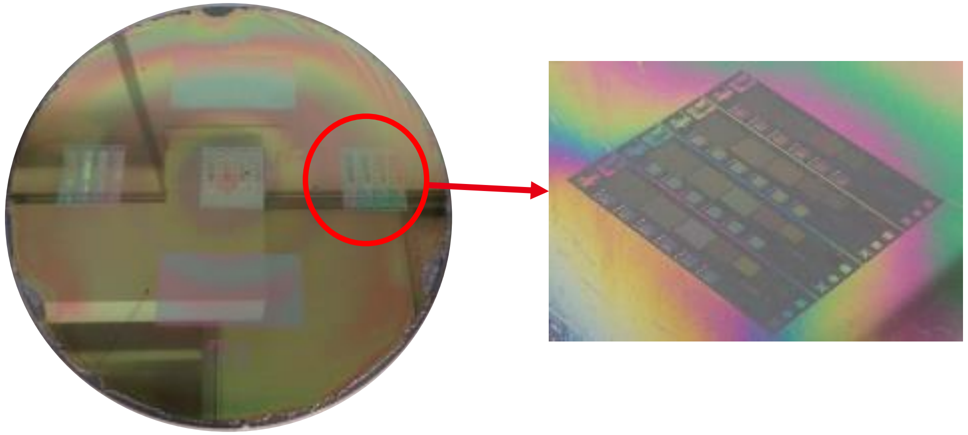




3- micro-LED patterning

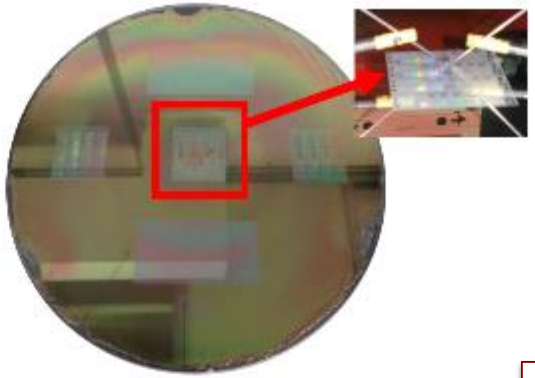
High precision microLED patterning
Plasma etch

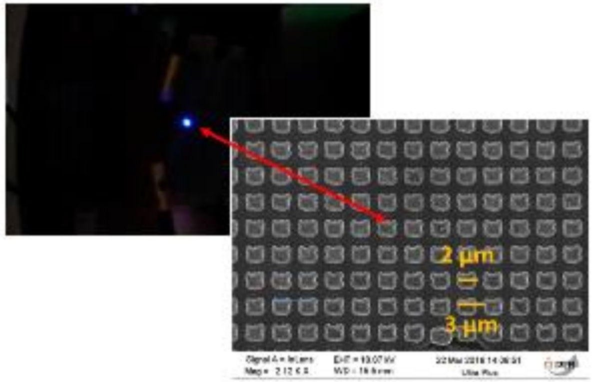


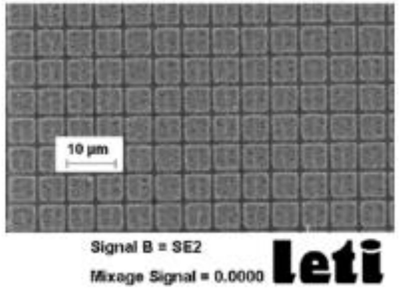


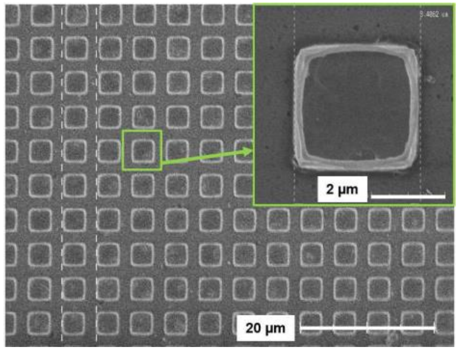
NOVEL APPROACH FOR GAN MICRODISPLAYS

Feasibility demonstration

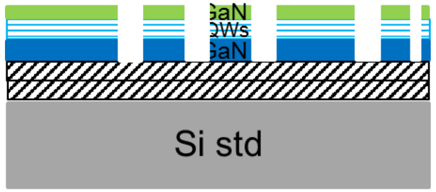


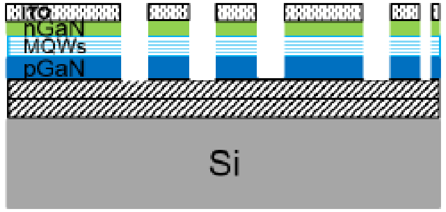




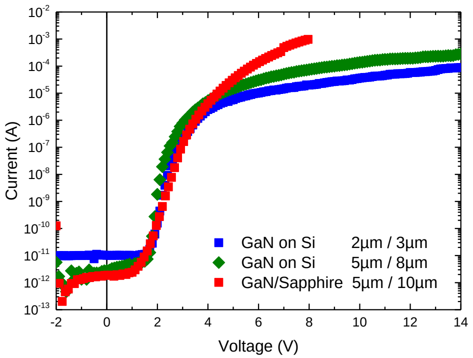


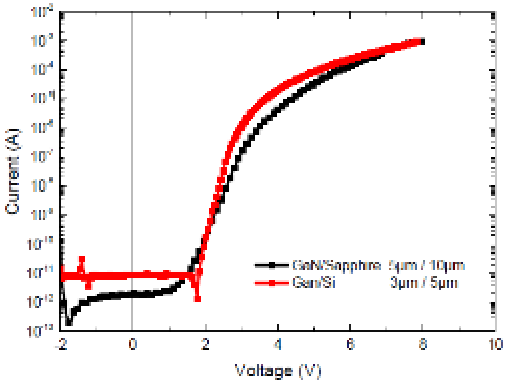
With ITO:





I (V) curves:



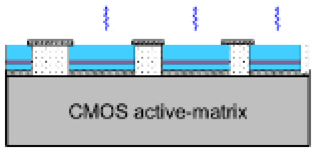


- ➢ **MicroLEDs operate after transfer process and post processing (patterning)**
- ➢ **Record pixel-pitch GaN microLED array (3 µm)**
- ➢ **Good Electrical characteristics**

→ Proof-of concept made

Next steps::

- **Active-matrix prototypes**

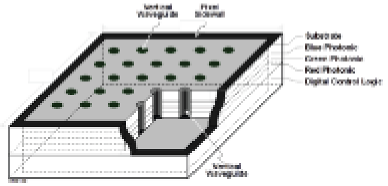


TECHNOLOGICAL BRICKS
THE COLOR CHALLENGE

- 3 colors on same wafer
- small pitch (10 / 5 / 3 µm)
- crosstalk

Direct generation:

- Stack of Three LEDs (Ostendo): Clever, but $$$



- Selective Area Growth (SAG)
- Nanowires
- InGaNOS

→ Medium/Longterm

Color conversion:

Phosphors, QDs

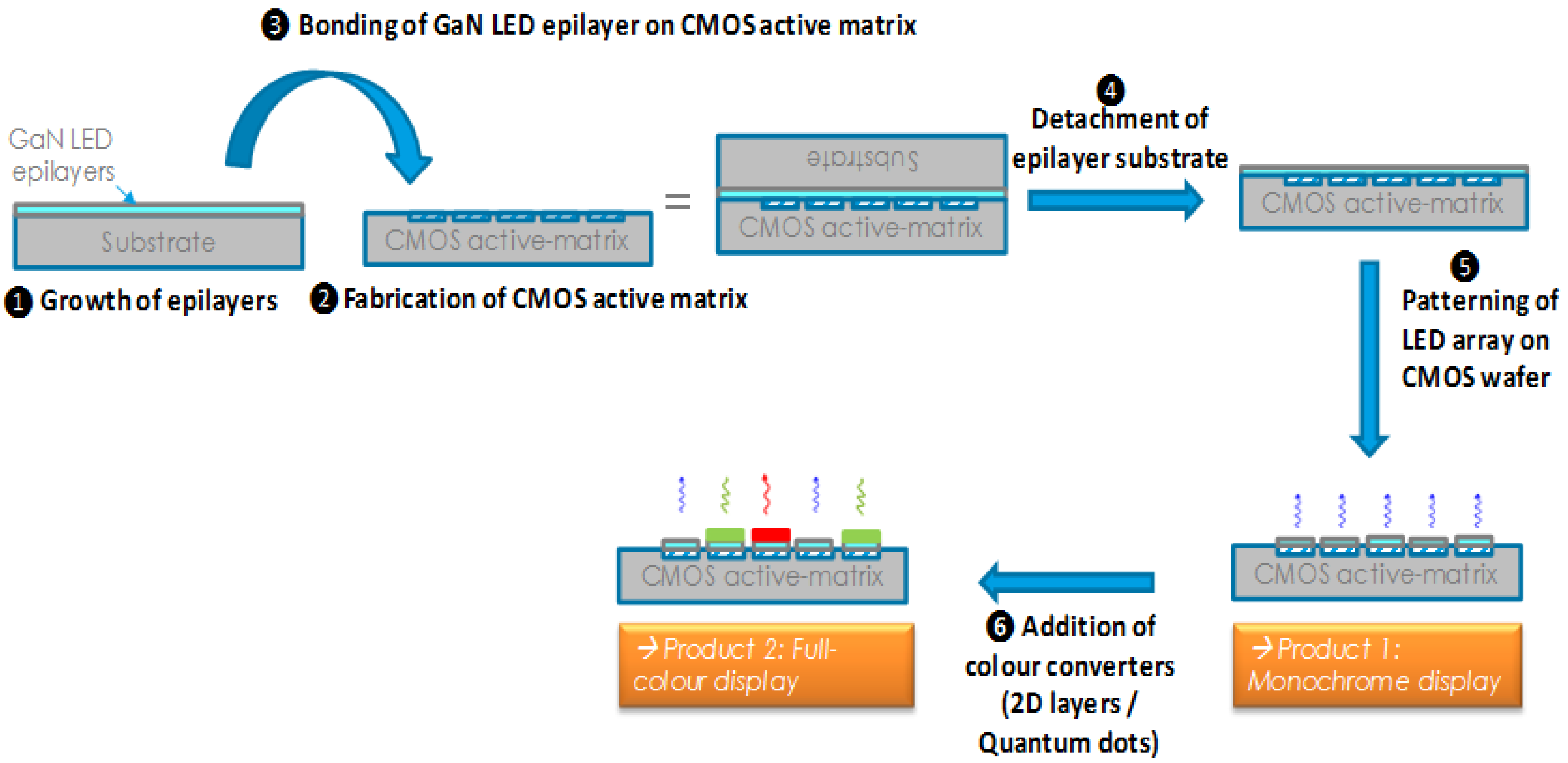
- Existing materials /Suppliers
- Good color saturation
- Lifte time?
- Pattern?

2D layers

→ MQWs Green : InGaN/GaN/saphire

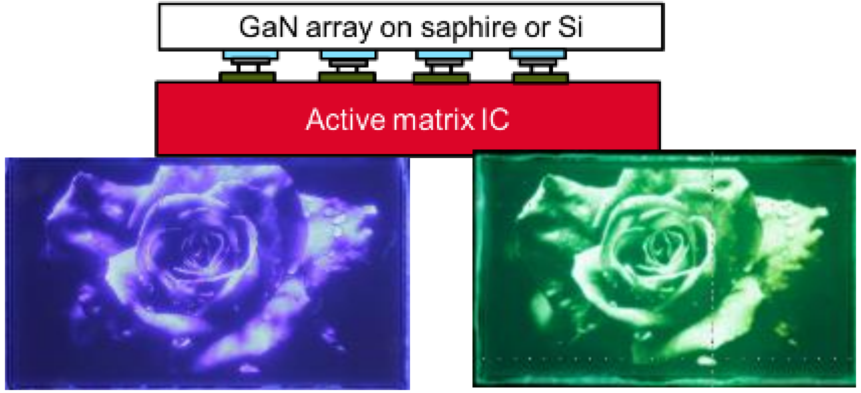
→ MQWs Red : InGaAlP/InGaP/GaAs

Overall process / approach



SUMMARY / CONCLUSION

2 technologies are developed for making high brighntess GaN microdisplays :

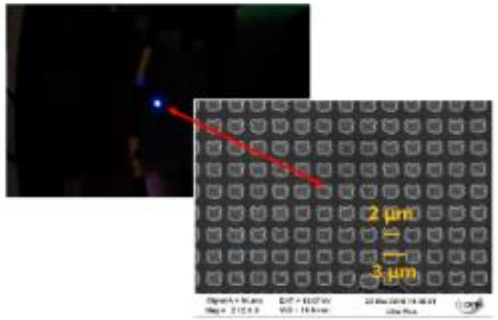


- **Hybridization technology**:
  - full active matrix WVGA, 10 µm pitch

  → can address some applications

- **Monolithic technology**: proof-of-concept made.

  Advantages:
  - very small pixel pitch
  - suitable for colour
  - suitable for any other feature: extraction enhancement, emission direction, …
  - full CMOS (industrialization, cost, ..)



- **Some challenges remain….color, …**

OUTLINE

- Introduction
- Challenges and (some) solutions for GaN microdisplays
  - LED microdisplays fabricated with hybridization technology
    - Gen1 and Gen2 GaN microdisplay demonstrators
  - LED microdisplays fabricated with direct bonding technology
  - Other challenges for microdisplays
- Challenges and (some) solutions for MicroLED displays
  - microLED Transfer process
  - microLEd display driving
- Conclusion

THE DISPLAY WORLD(S)

MicroLED displays

displays

What are the motivations?

WHY MICROLED DISPLAYS?

Depends on application....

	Smartwatch	Smartphone	Laptop and tablets	TVs	VR	AR	Automotive HUD	Video displays
Energy consumption	5	4	4	1	3 (un-tethered)	5 (un-tethered) [1]	1	4
High Pixel Density	2	2	1	1	5	5	0	0
Color Gamut	2	2	3	5	4	4	1	4
Brightness	5	4	3	4	0	5	5	4
Contrast	3	3	3	5	3	3	3	4
Refresh rate	1	1	2	5	5	4	1	1
Long lifetime	1	1	2	2	2	2	5	5
Flexible	3	3	0	0	1	1	1	3
Overall attractivness	22	20	17	23	24	29	17	25

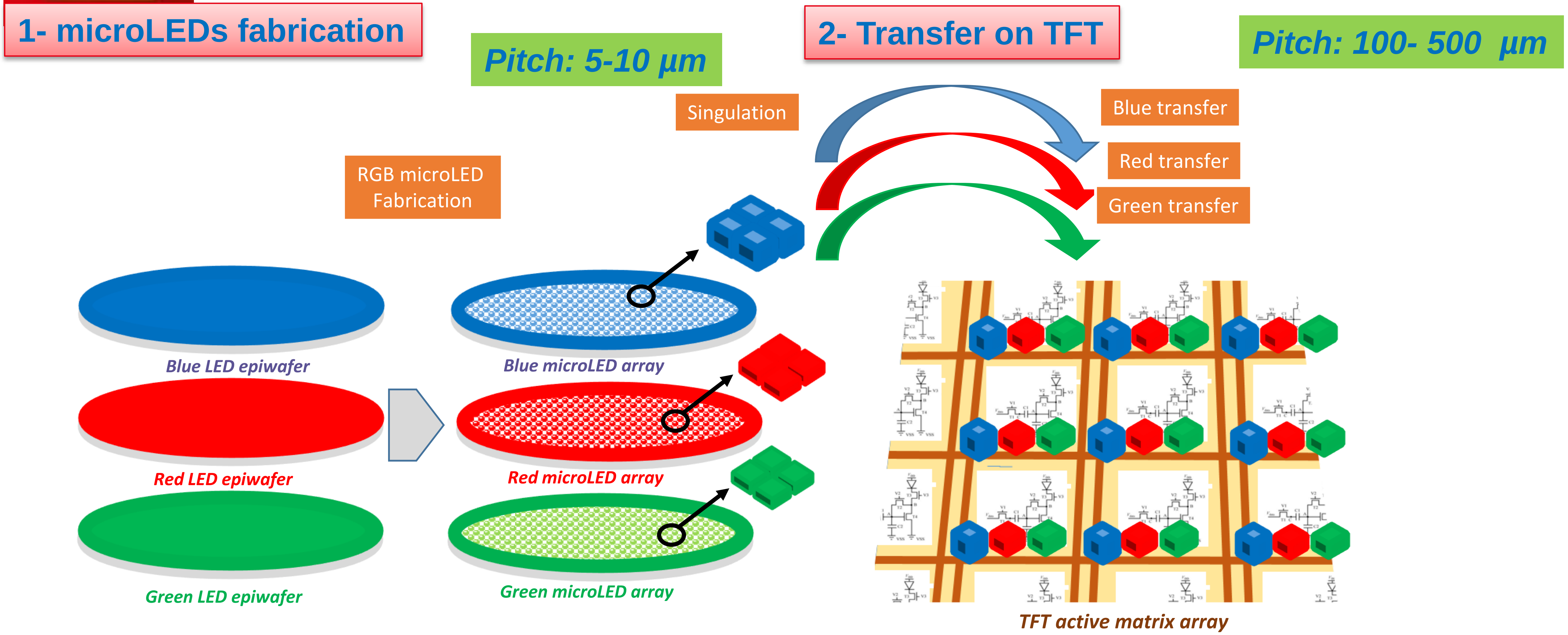
[1]: expect longer use periods than VR

1 - Not very important or differentiating
2 – Important
3 – Very important
4 – Critical
5 – Strong differentiator

YOLE

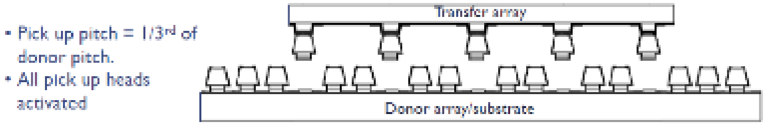
Image quality is the main target

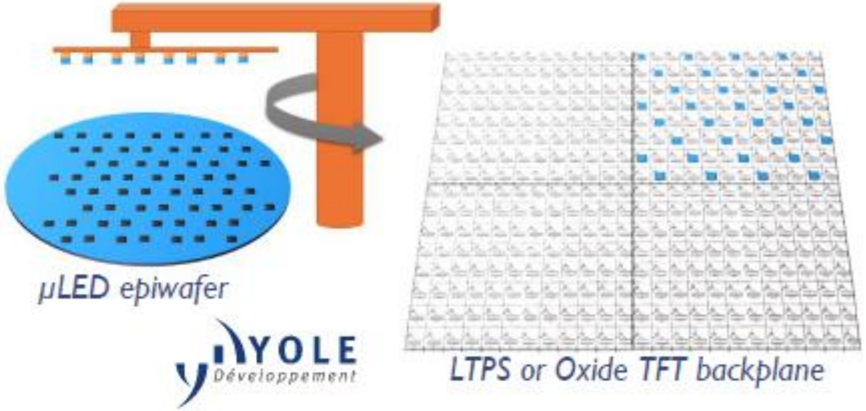
INTRODUCTION : LED DISPLAYS: GENERAL APPROACH



CHALLENGES IN THE TRANSFER PROCESS

Low to Mid Pixel density: Pick and Place





Principle:
1-Select a series of MicroLEDs on donor (→ other pitch)
2-Transfer onto TFT plate (large pitch)
3-Select a new series
4- Transfer on new field on TFT
Etc..
.....Repeat for other colors

2 key features:
1- ensure mechanical contact + electrical contact
2- numbers: TV HD: 6+ millions; 4K: 24 M…→ go fast, yield

MICROLED DISPLAYS: KEY CHALLENGES

How LETI addresses them?

→ RGB microLED performance

- Brightness, EQE, …
- For very small size devices
- For the three colors…

→ develop high quality RGB microLEDs
→ investigate size reduction effects

→ transfer process:

- Yield (99.9999…)
- Throughput (mass production)
- Cost (consumer)
- Connection?

→ Evaluate transfer process with microtube technology
→ Evaluate transfer process with reduced step approach

→ microLED display driving

- High brightness means …high currents
- Led homogenity issues: brightness , wavelength, …

→*Driving very challenging*

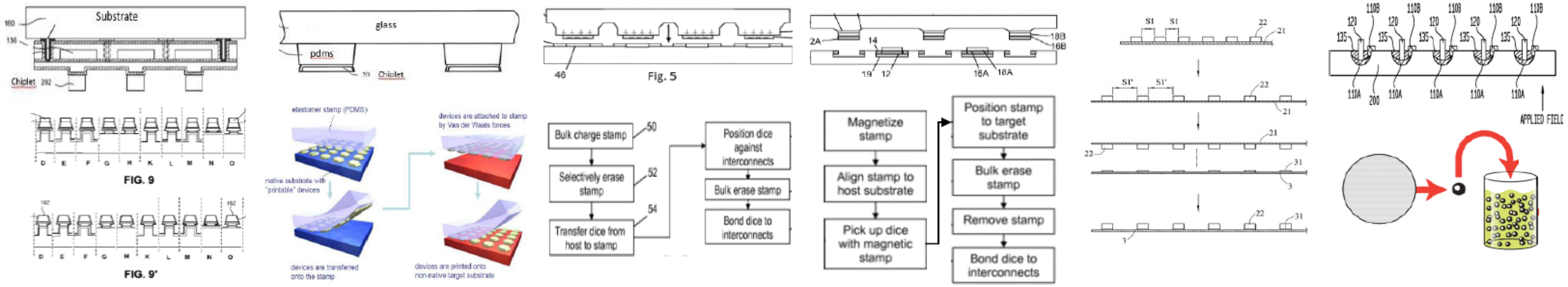
→ Evaluate a disruptive approach where microLEDs are CMOS driven

OUTLINE

CHALLENGES IN THE TRANSFER PROCESS

Multiple technologies have been proposed to exert the pick up force on the die:

Electrostatic MEMS	Elastomer stamp	Electrostatic Stamp	Magnetic/Electromagnetic	Adhesive	Fluidic Assembly
LuxVue-Apple	U of Illinois, X-Celeprint, Semprius, Cooledge, AUO, CSOT, ITRI	Cooledge, AUO	Cooledge, PlayNitride, ITRI	PlayNitride, Intel	Nth Degree, Sharp, PSI
The LuxVue process uses an electrostatic pick up head. The die is released via the local phase change of a bonding layer (e.g. from solid to liquid or at least a more malleable state).	The X-Celeprint process uses Van Der Walls forces. The die is released by breaking an anchor. Cooledge process also suggest release by breaking anchor or through laser lift of.	A transfer stamp is charged with a spatial pattern of electrostatic charge. The stamp may be bulk charged and then selectively discharged using irradiation through a patterned mask.	The stamp is an array of magnetic or electro-magnetic transfer posts (MEMS form or passive stamp). LED die are magnetized by coating and patterning a suspension of magnetic particle in photoresist.	The stamp is a stretchable adhesive film. The μLED are picked up by the film which is then stretched along the X and Y direction to match the pitch of the receiving substrate before release of the die.	μLED in a suspension in a fluid are deposited at the surface of substrate featuring micro cavities and/or circuit traces. The μLED are dipoles and can be aligned with an electromagnetic field

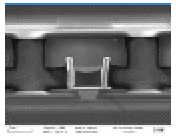


1- Connection

In general, bonding of microLEDs on final substrate (TFT) is very tricky (release from transfer carrier)

In most cases, electrical connexion is not made at this step → needs further processing

A connection approach where strong mechanical bonding + electrical connection are provided in a single step is highly desirable

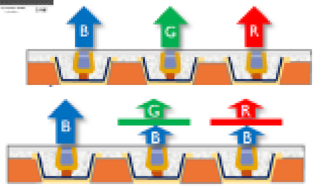


It exists!

2- Throughput

In general, only one color is transfered at a time → long

Why not transfer three colors in one step?



→ 3 transfers

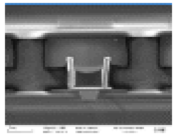
→ 1 transfer

CHALLENGES IN THE TRANSFER PROCESS

Transfer process with microtube technology

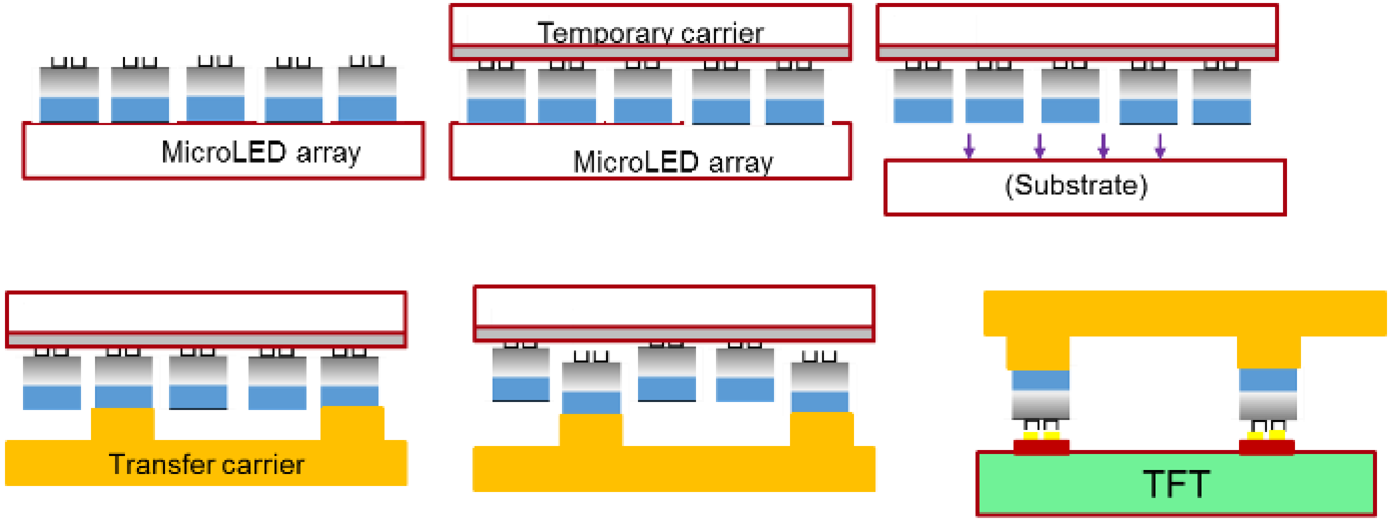
Key advantages:

- Microtubes makes both electrical and mechanical connection
- Reliable / proven technology for microdisplays / sensors
- Room temperature process



Microtubes can be grown on microLED wafer
→ Easy process for the connecting pad on the TFT side

Example of implementation:

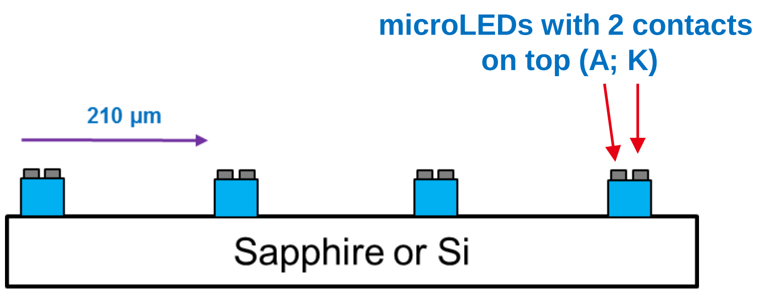


CHALLENGES IN THE TRANSFER PROCESS

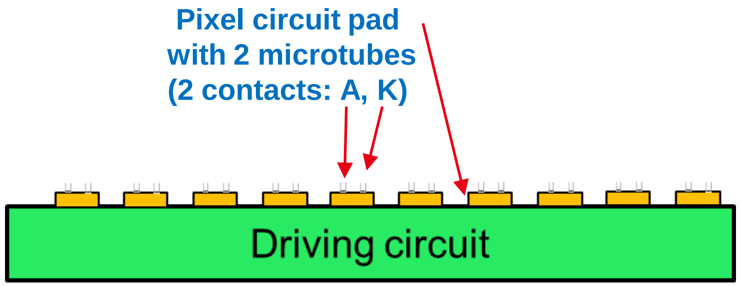
Transfer process with microtube technology

Proof of concept

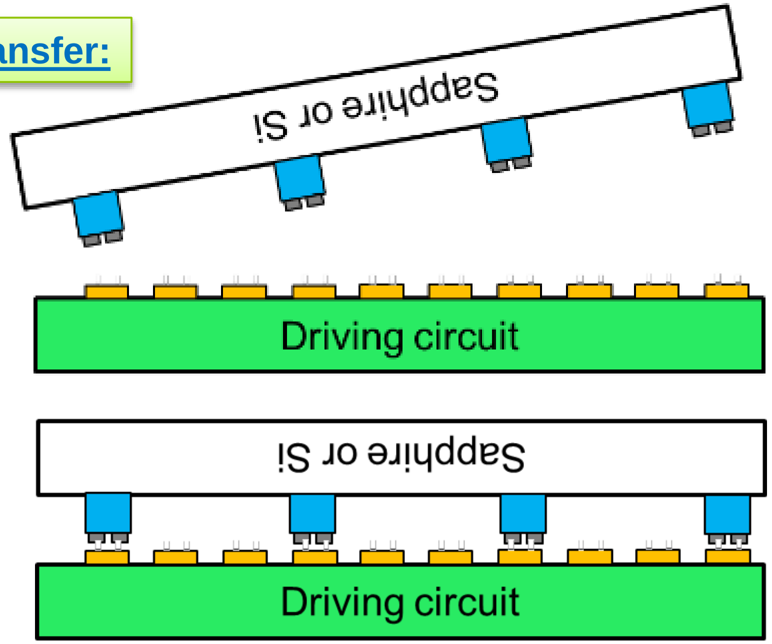
1- MicroLED fabrication:



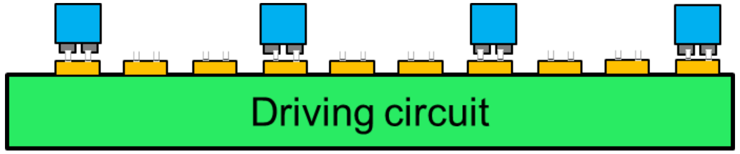
2 - Driving circuit fabrication:



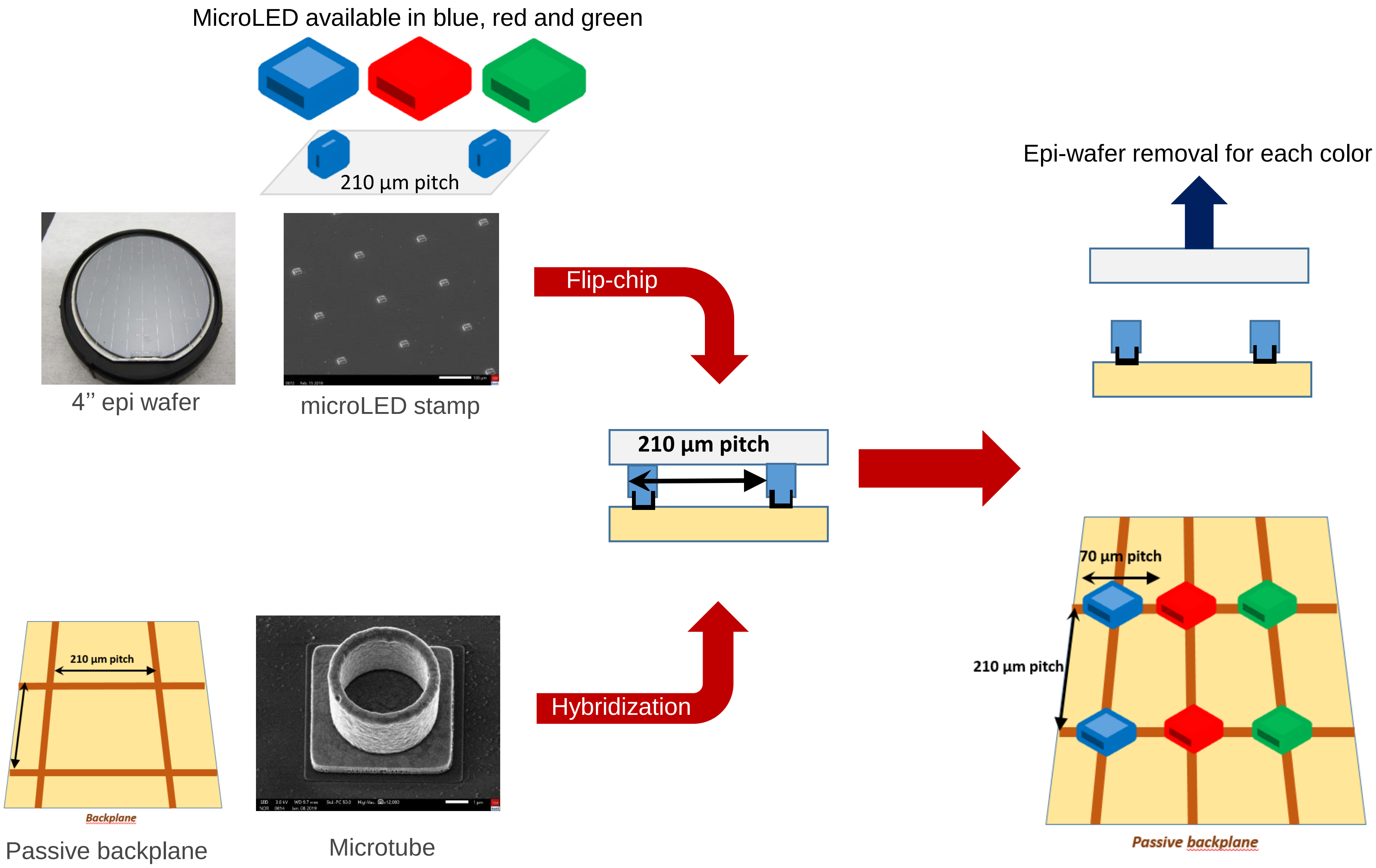
3- Transfer:



4- Substrate removal:



Proof of Concept for large area display on passive backplane

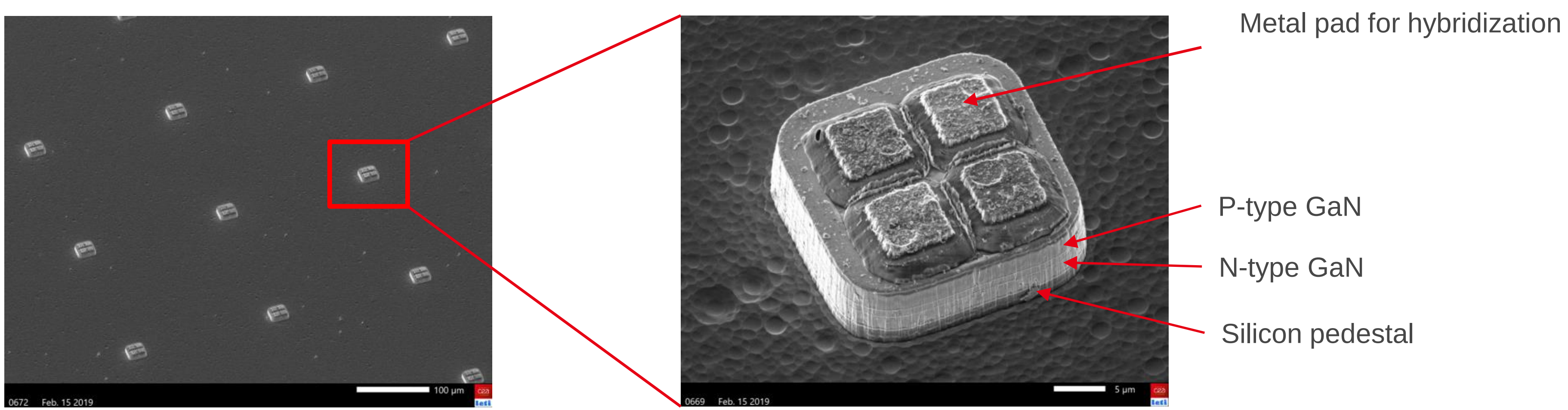


CHALLENGES IN THE TRANSFER PROCESS

Transfer process with microtube technology

Proof of concept

1- MicroLED fabrication:



MicroLED array – 210µm pitch

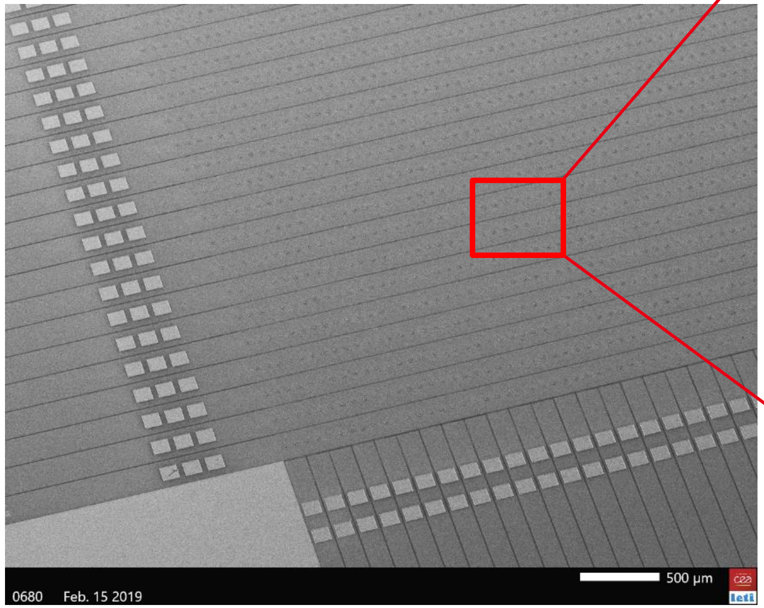
Single MicroLED (25µm side)
with 4 metallic pads on the top side

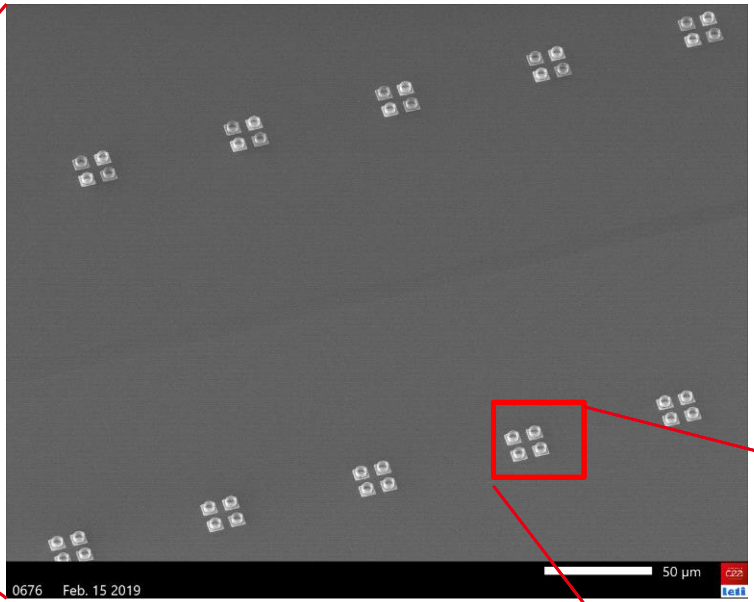
J. Bernard et al., Display week, 2019

Process upside down (GaN on Silicon)

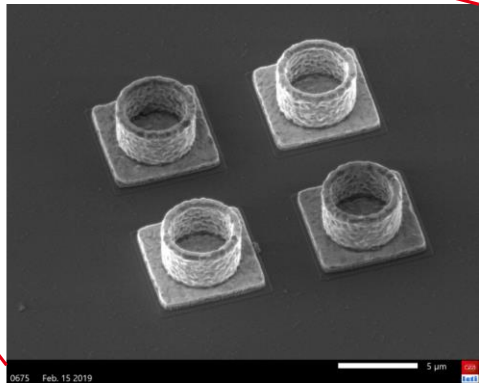
- Patterning and deposition the N-contact metal down to N-type GaN + insulation
- Patterning and deposition the P-contact metal + insulation
- Patterning and deposition the vias and metal pad for hybridization

PASSIVE BACKPLANE





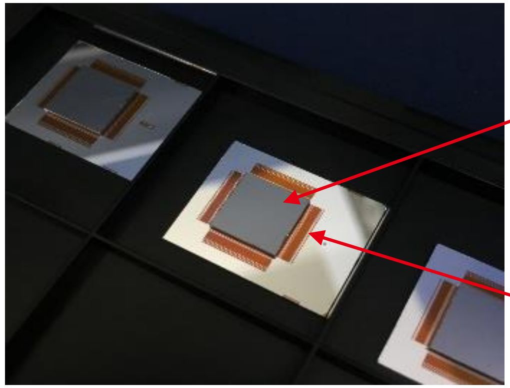
Microtube with 10µm pitch



- **X, Y matrix**
  - 210µm pitch in Y and 70µm pitch in X for RGB
- **Standard silicon technology**
- **With microtubes on top side**

➢ **4 microtubes for mechanical stability**

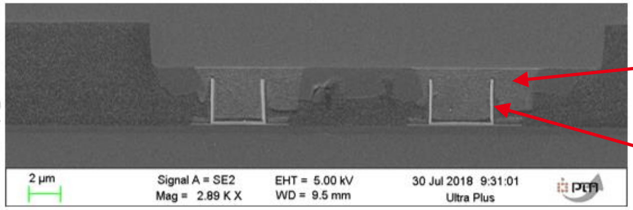
HYBRIDIZATION



Stamp (64mm²) with MicroLEDs

Passive matrix with Microtubes

Cross section view
of microtubes hybridize on pads

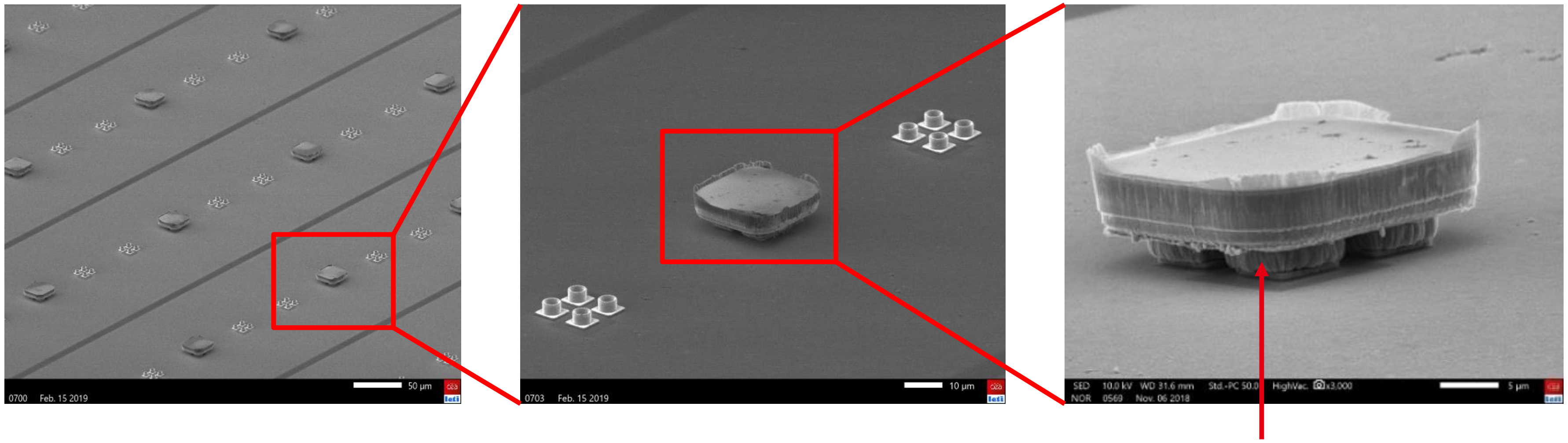


Pad for hybridization

Microtubes

- **Collective Flip-chip hybridization**
  - Transfert of 1600 microLEDs in 1 step

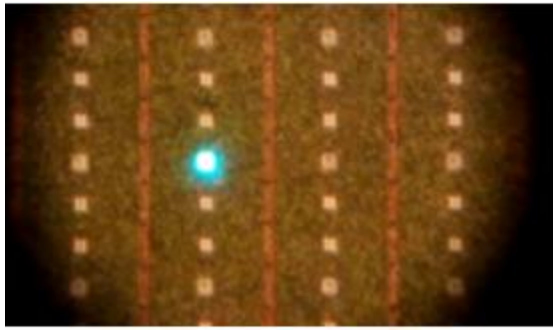
MicroLED Liberation from epitaxial substrate

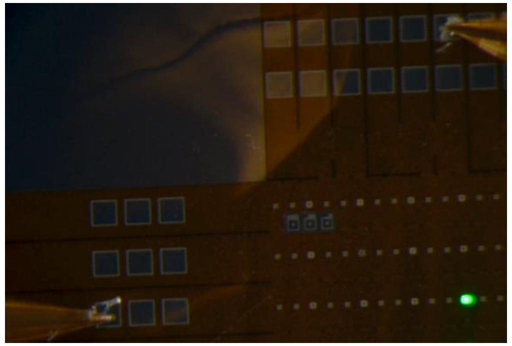


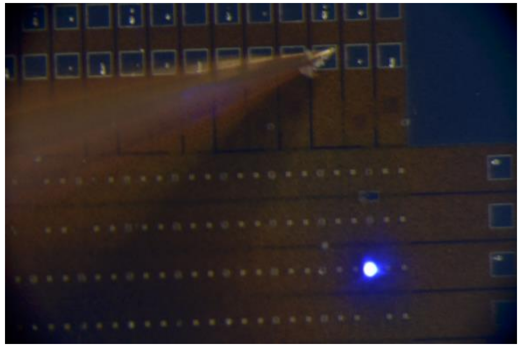
Microtube interconnections

- **Liberation**

RESULTS







➤ **Operating in green and blue**

→ Microtube suitable for microLED display

Next steps:

- **Full color transfer**
- **Transfer on Active matrix**

OUTLINE

OUTLINE

❑ Challenges for driving microLED displays

INTRODUCTION MICROLED DISPLAYS: KEY CHALLENGES

2- Driving electronics performance

New specifications | **New technology / material**

New specifications:

High resolution — HD, 4K, 8K, …
higher frame rates (60, 120 Hz,…)
→ *higher operating speed for the electrical driving at the pixel level.*

High Dynamic Range (HDR) → higher brightness
→ *higher levels of current to be supplied*

→ Driving electronics under new constraints

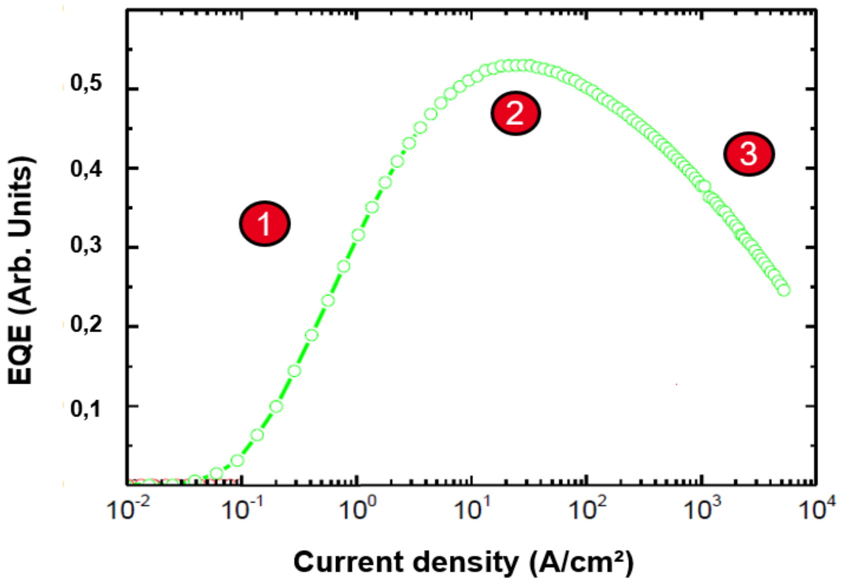
CHALLENGES IN THE MICROLED DISPLAY DRIVING

New technology / material InGaN; AlInGaP

1-specific luminance response

2-Inhomogeneities / variability

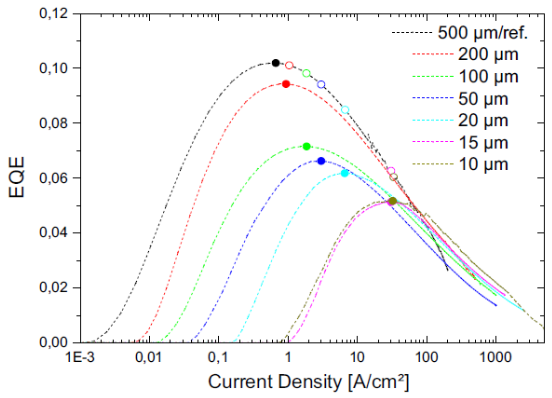
specific luminance response



EQE as a function of current density for a 20-μm size blue-emitting InGaN microled

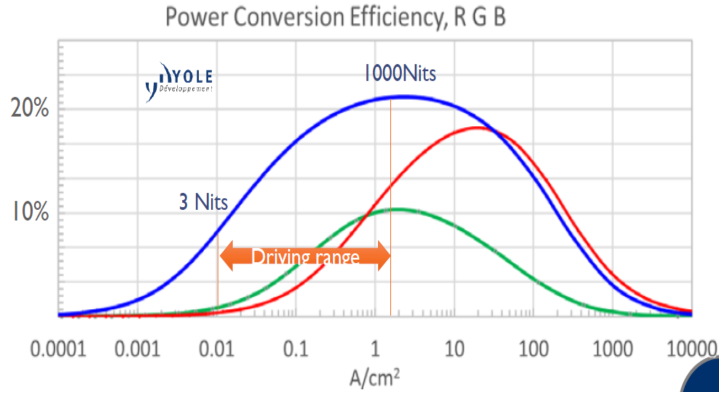
1. non-radiative recombinations, resulting from defects at the periphery of the devices
2. peak efficiency (Regime 2, obtained around a few A/cm
3. Auger-effect

Size-dependance



How to drive?

Color dependance



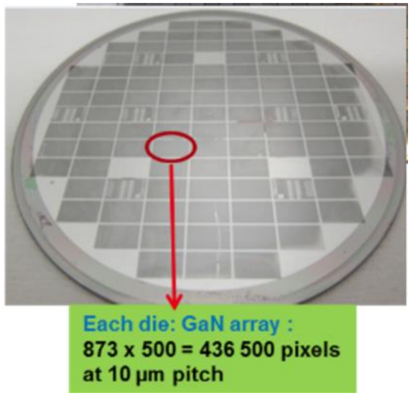
CHALLENGES IN THE MICROLED DISPLAY DRIVING

New technology / material InGaN; AlInGaP

2-Inhomogeneities / variability

I-V-L curves: variability

GaN microLED arrays for microdisplays



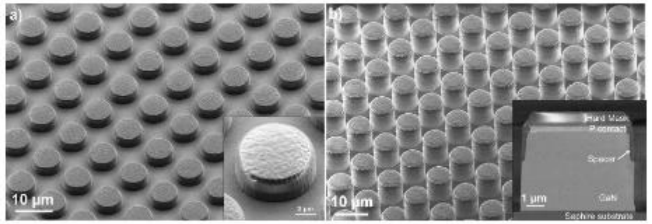
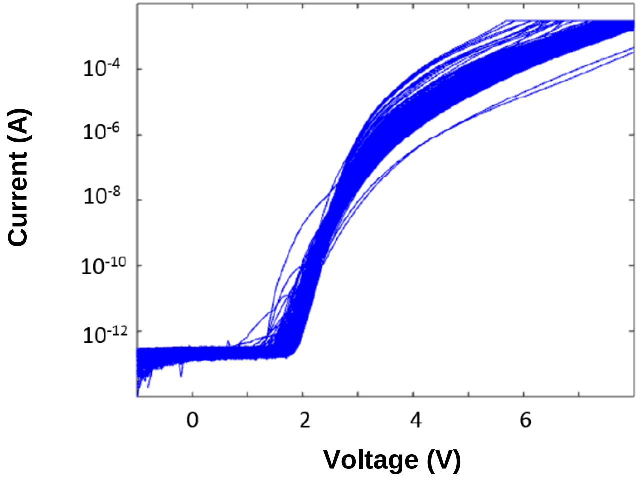
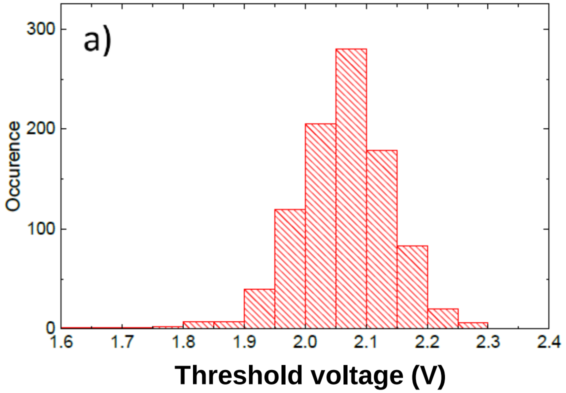
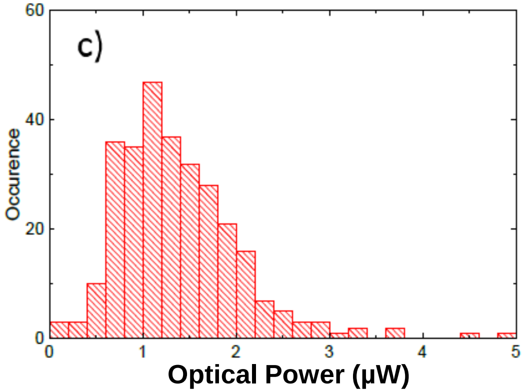


Figure 3. SEM images of 8 µm pixels at a pixel pitch of 10 µm after spacers formation. (a) The GaN mesa is 1 µm deep, inset is a zoom on a single µLED (b) The GaN mesa is etched down to the sapphire substrate, inset is a cross sectional view of a pixel revealing the internal structure.

~ 1000 µLEDs tested on one matrix:
1st Gen, 6 µm size, 10 µm pitch







Wavelength variability:

Addition of 3 primary colors
→ Each color very homogeneous (~1-2 nm) or compensated?

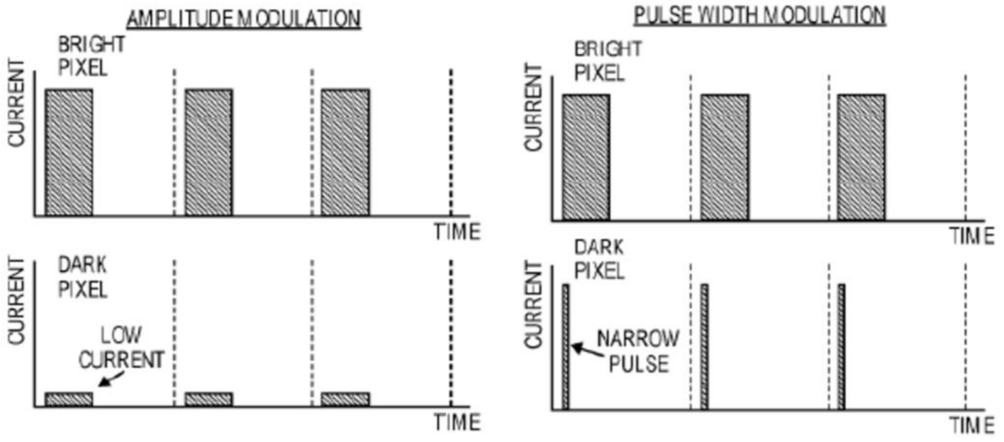
CHALLENGES IN THE MICROLED DISPLAY DRIVING

Solutions for microLED display driving:

Analog amplitude modulation : not suitable

Solution: Pulse Width Modulation (PWM):

→fixed current
→brightness level = duty cycle



Extremely fast switching : microLED device OK (nsec) → **high bit rate/high gray scale**.

Current density set at peak efficiency

No blue shift.

Combined with compensation circuit, **PWM can potentially solve all the challenges of the microLED display driving.**

But… such circuits are ***much more complex***: more transistors + in-pixel memory and ***require very high quality transistor performance***.

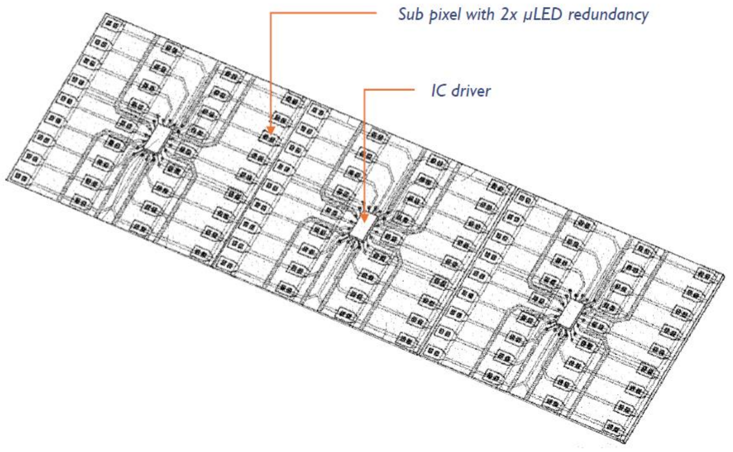
Therefore… **TFT not sufficient?** **→ CMOS technology**

CHALLENGES IN THE LED DISPLAY DRIVING

microLED CMOS driving: Existing solutions

Micro ICs transferred on the substrate:

LuxVue



A µLED display where discrete ICs positioned on the front face drive groups of 36 subpixels featuring a 2x redundancy.
(Source: LuxVue patent US 9,318,475)

Source: Yole

X-Celeprint

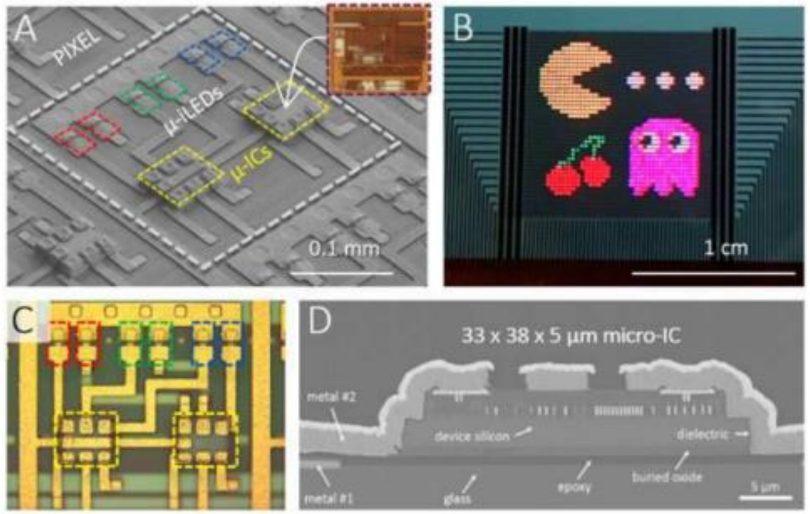


FIGURE 23 — Active-matrix microscopic inorganic light-emitting diode display on a glass substrate. The left micrographs (A, C) show a pixel with redundant control and emitters. Each controller separately controls a group of three microscopic inorganic light-emitting diodes (µILEDs) (each pair of µILEDs of a common color are adjacent). The upper right photograph (B) shows the entire uncompensated operational display and (D) is a cross section of the controller.

C. Bower et al., "Emissive displays with transfer-printed assemblies of 8 µm × 15 µm inorganic light-emitting diodes", Photonics Research, Vol. 5, N°2, pp A23-29 (2017)

CHALLENGES IN THE LED DISPLAY DRIVING

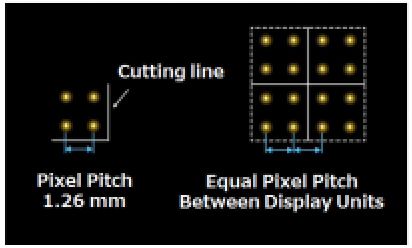
microLED CMOS driving: Existing solutions

SONY Cledis

Micro ICs transferred on the *tile*:

"Technologies for the Crystal LED Display System",
Goshi Biwa et al.; Display Week San Jose 2019

"RGB micro LEDs and <u>microscale IC (micro IC)</u> have been placed in each pixel and integrated into the active matrix system"



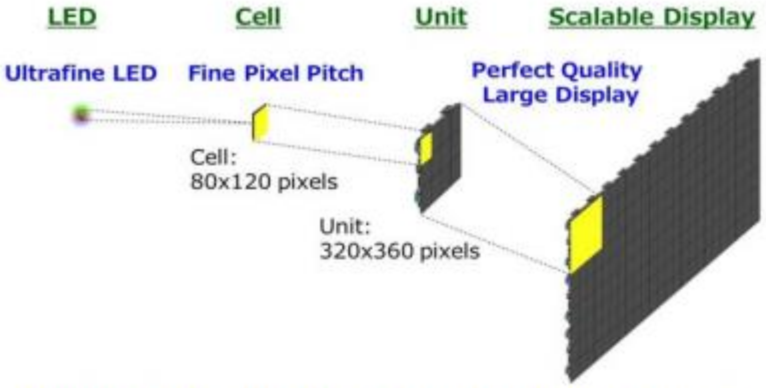


Figure 3. Structure of the Crystal LED display system.

Figure 2. Crystal LED display system commercialized as a scalable display system.

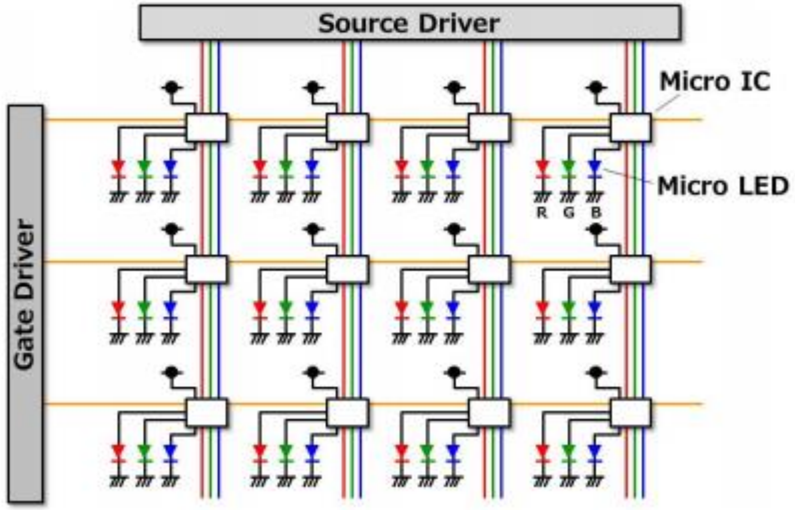


Figure 8. Example of active matrix driving using RGB micro LEDs and the micro IC in each pixel.

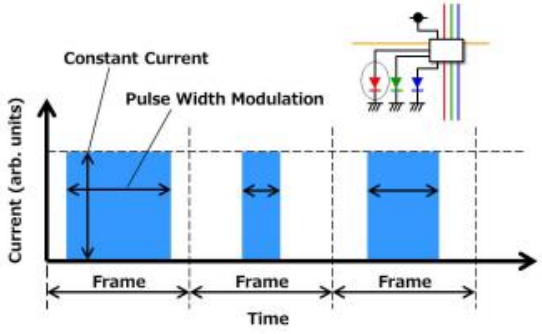
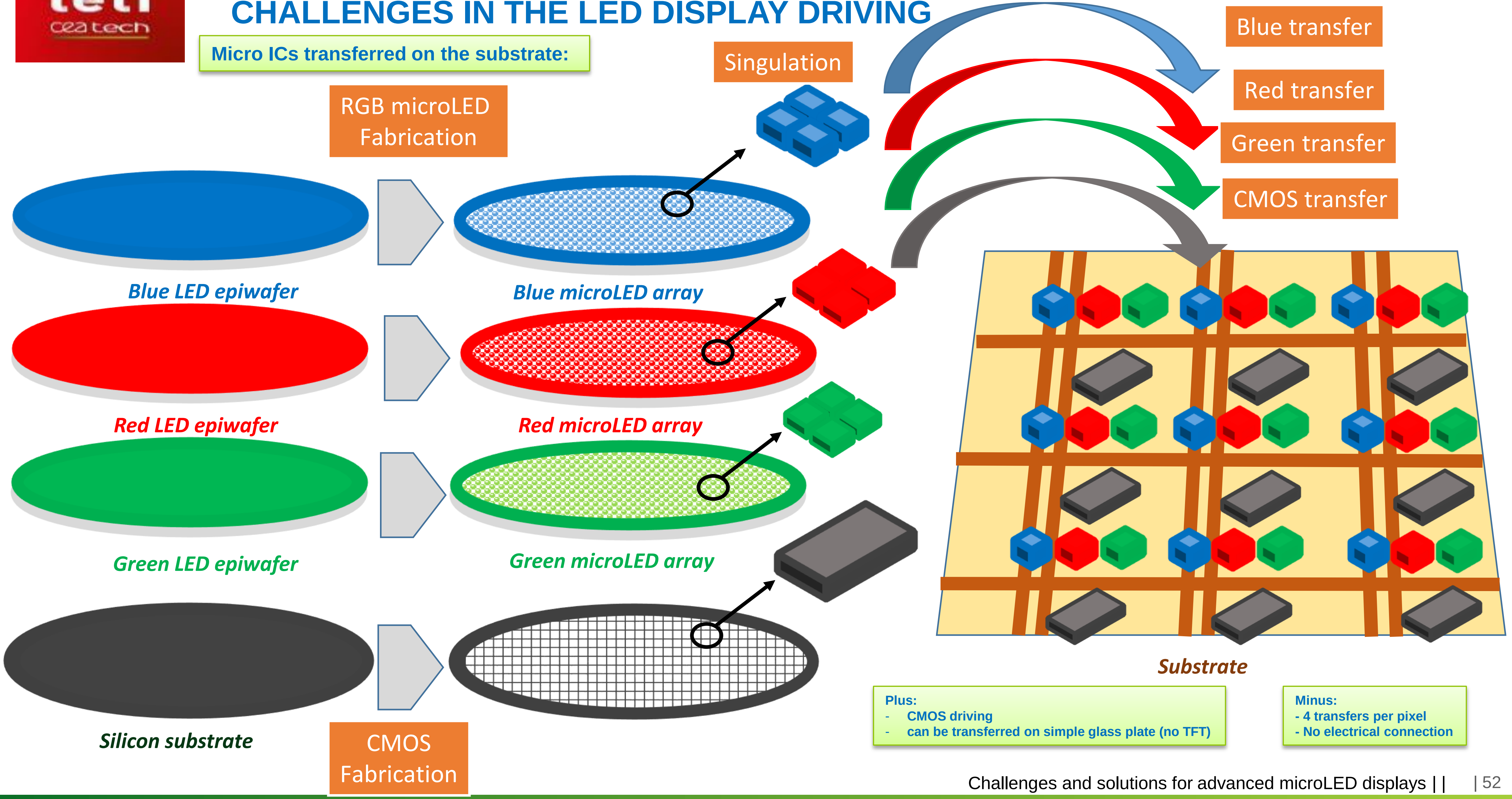


Figure 9. Example of constant current pulse width modulation of the micro LED by the micro IC.

"Integrating these novel active matrix driving and video processing controls such as dithering has achieved superior linearity even below 0.01 up to 1000 cd/m2"

CHALLENGES IN THE LED DISPLAY DRIVING

Micro ICs transferred on the substrate:



Plus:
- CMOS driving
- can be transferred on simple glass plate (no TFT)

Minus:
- 4 transfers per pixel
- No electrical connection

OUTLINE

- ❑ Driving microLED displays: a new solution

CHALLENGES IN THE LED DISPLAY DRIVING

New LETI solution:

New concept:

Driving circuit is *embedded* with the microLED

The transferred unit includes: RGB microLEds *and* the CMOS driving circuit

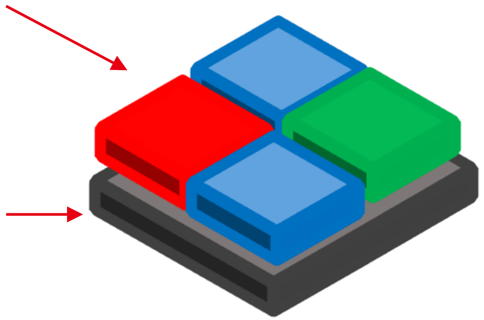
How?

1- Elementary unit:

All-in-one RGB LEDs *on* CMOS

RGB microLEDs

Driving circuit



2- Transfer of Elementary unit:

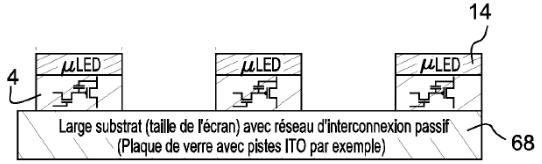


Fig. 6I

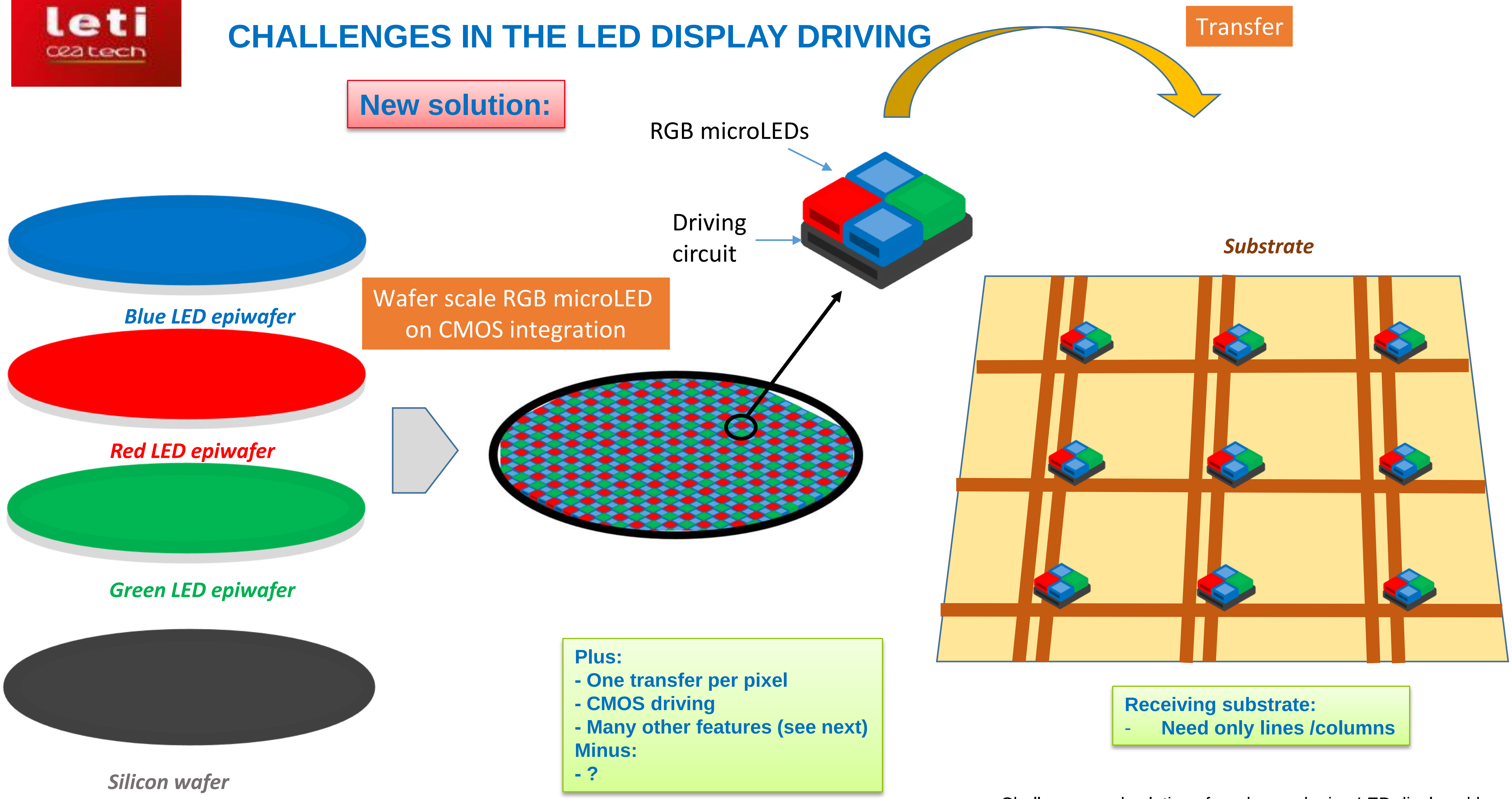
(10) Numéro de publication internationale
WO 2017/089676 A1

OUTLINE

- ❑ Fabricating high performance microLED displays

CHALLENGES IN THE LED DISPLAY DRIVING

New solution:



Plus:
- **One transfer per pixel**
- **CMOS driving**
- **Many other features (see next)**

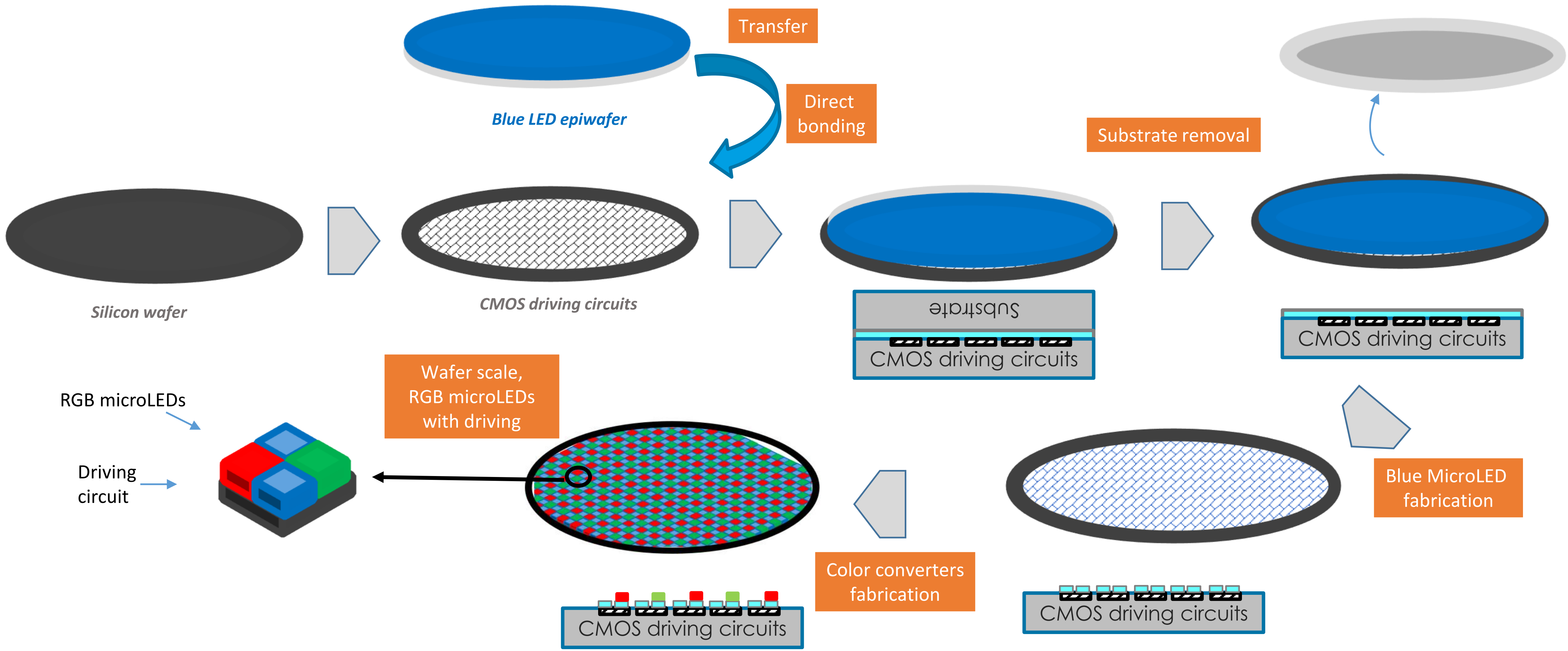
Minus:
- **?**

Receiving substrate:
- **Need only lines /columns**

CHALLENGES IN THE LED DISPLAY DRIVING

LETI solution

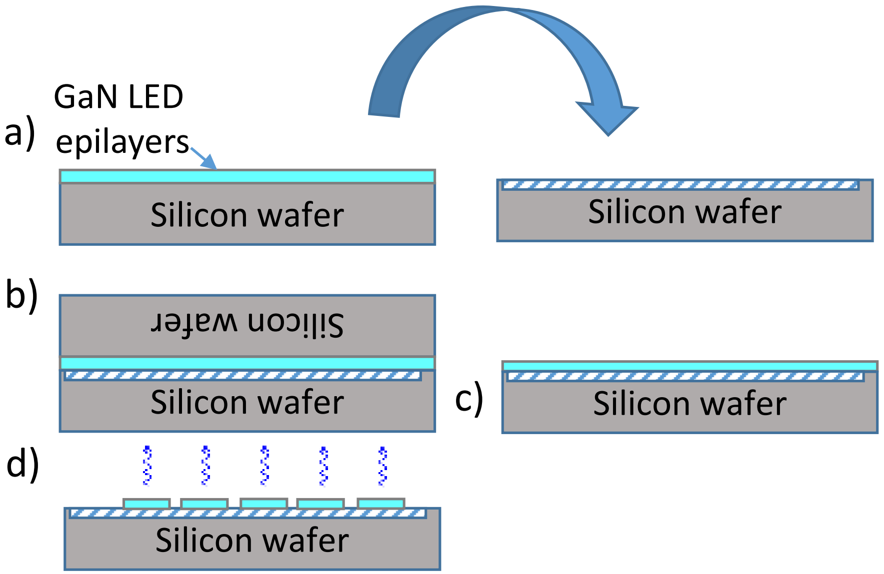
Wafer-scale, RGB microLED-on-CMOS integration

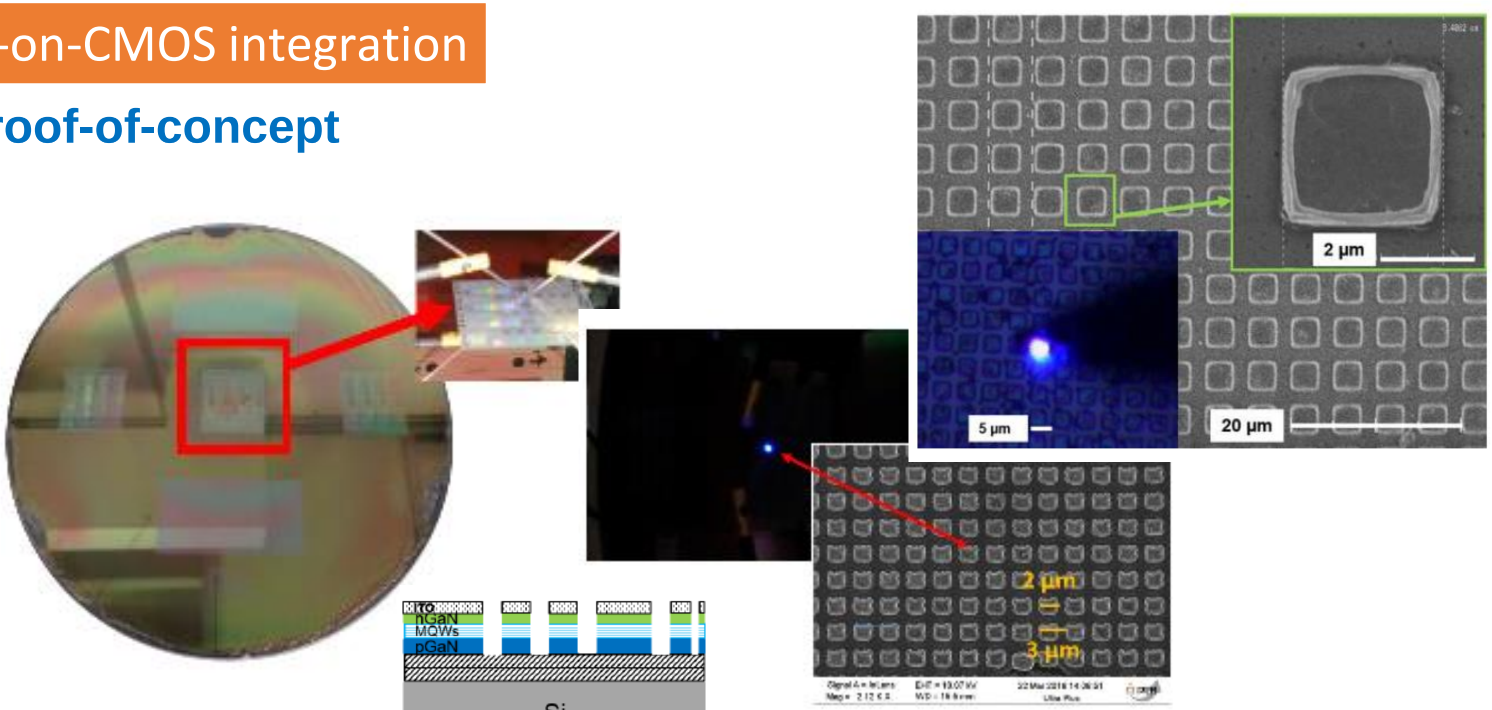


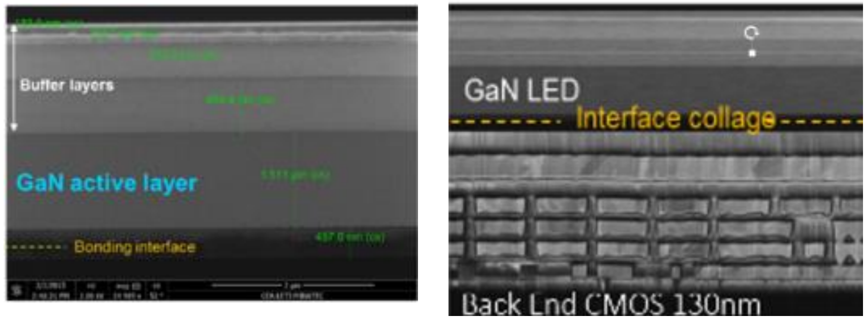
CHALLENGES IN THE LED DISPLAY DRIVING

Wafer-scale, RGB microLED-on-CMOS integration

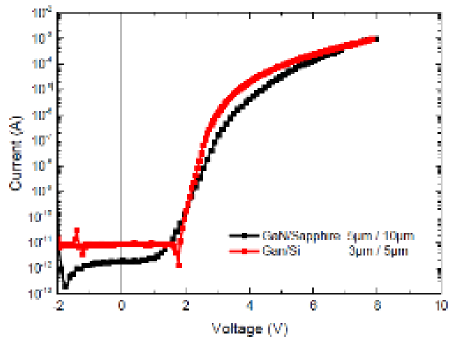
Proof-of-concept







Display Week 2017



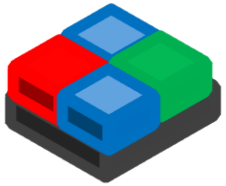
Proof-of-concept for fabricating full CMOS microLED units

OUTLINE

- ❑ Advantages of the new solution

ADVANTAGES OF THE NEW SOLUTION

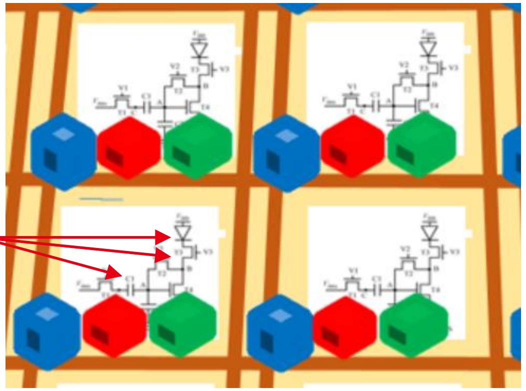
MicroLED are directly stacked onto the circuit:



→ **Shortest connection (fast, PWM)**

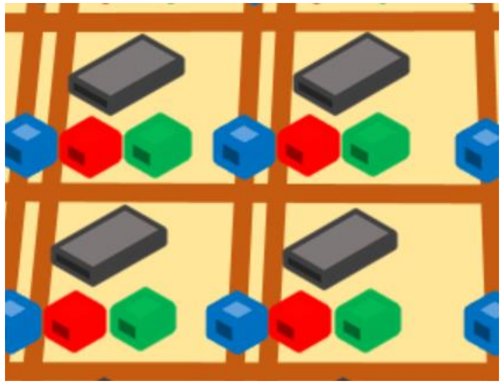
→ **Best fill ratio**

µLED + TFT

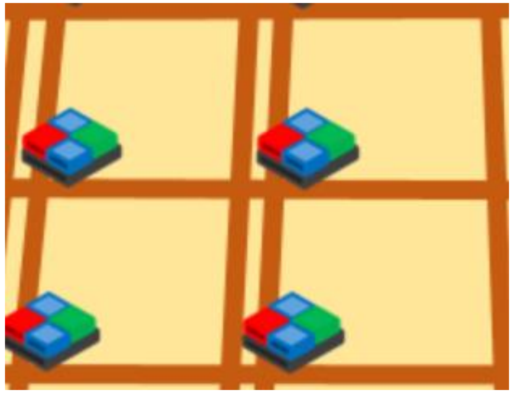


TFTs

µLED + CMOS



µLED on CMOS



Biggest transparent area → Transparent displays

Less reflective part (contrast) → Ultra-high contrast displays

CHALLENGES IN THE LED DISPLAY DRIVING

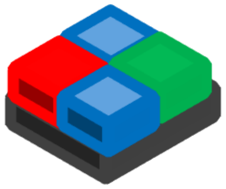
ADVANTAGES OF THE NEW SOLUTION

Performance….

MicroLED for Direct view displays:

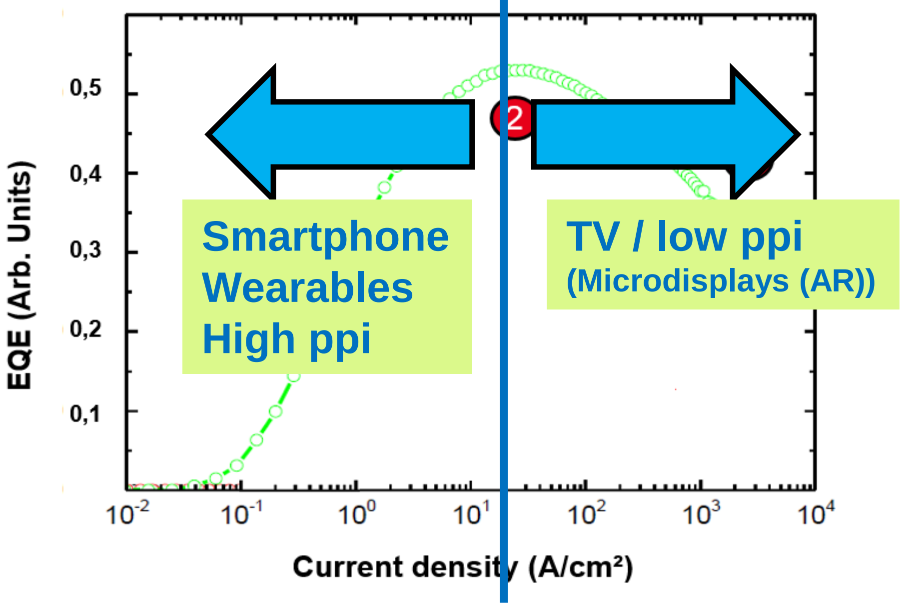
Emitting surface ≠ pixel area

Nits? at what level?



500 – 1000 nits (Display)→

Nits at µLED level strongly depend on application
Same for curent density….



Advantage of CMOS:

Make complex circuit (PWM…)
compact

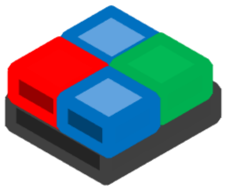
Make performant circuit: IGZO limited to 15 cm²/V.s
High mobility + short distance : less signal (pulse) distortion
→ Image quality

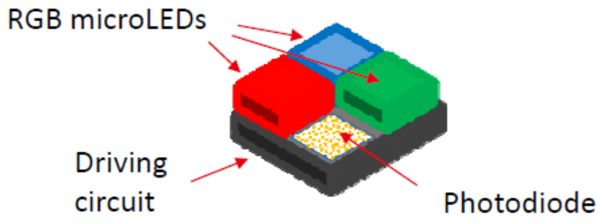
CHALLENGES IN THE LED DISPLAY DRIVING

ADVANTAGES OF THE NEW SOLUTION

Additional functions:

The elementary unit can embed sensing, actuating,…





All CMOS compatible

- → **Haptics on display**
- → **Sound on display**
- → **….**

Display yield and testing:

Necessary to identify "Known Good Dies" after microLEDs after fabrication

Wafer level fabrication → **Embedded, contactless testing possible**

Mass transfer technology:

- → **1 transfer instead of 3 or 4**
- → **Transfer technology-agnostic,**
- → **CMOS: possible to fabricate anchors, tethers.**

CHALLENGES IN THE LED DISPLAY DRIVING

ADVANTAGES OF THE NEW SOLUTION

New receiving substrate: A simple substrate with only columns and lines

- **Low cost:** non-lithographic techniques: ink-jet, stencil printing, …
→ lower investment level required to enter the display market

- **No size limit:** Today TFT at GEN10.5, ok for 65/75-in. TVs. Not for 100-in. or bigger TVs.
With the simple substrate, no size limit.
→ A can be a game changer for microLED displays?

- **Freedom of material**: : glass, plastic, metal; rigid flexible, …
→ New applications…

Conclusion for microLED for large area displays

Strong challenge for transfer process, connections:
→ Microtube technology suitable

Strong challenge for driving microLED displays:

New solution: all-in-one RGB-on-CMOS unit:

- **helps solutioning driving**
- **many more features: applications, functionnalities,…**

Next steps: full integration….

Thank you for your attention!