CS INTERNATIONAL CONFERENCE
ANGELTECH
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Making monolithic RGB displays with InGaN

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Soft-Epi Inc.

2024.04.16

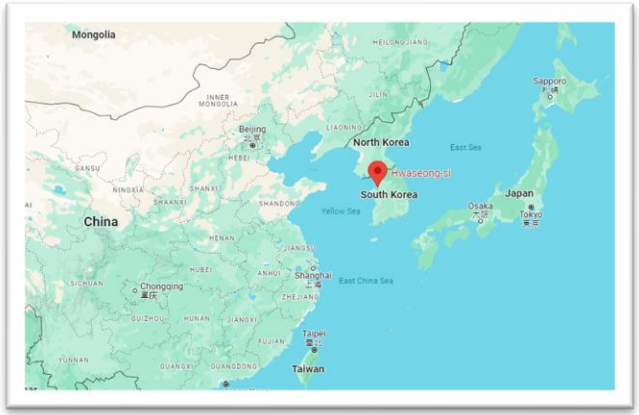
Soft-EPi

Company with Unique GaN Epitaxial Technology

Location

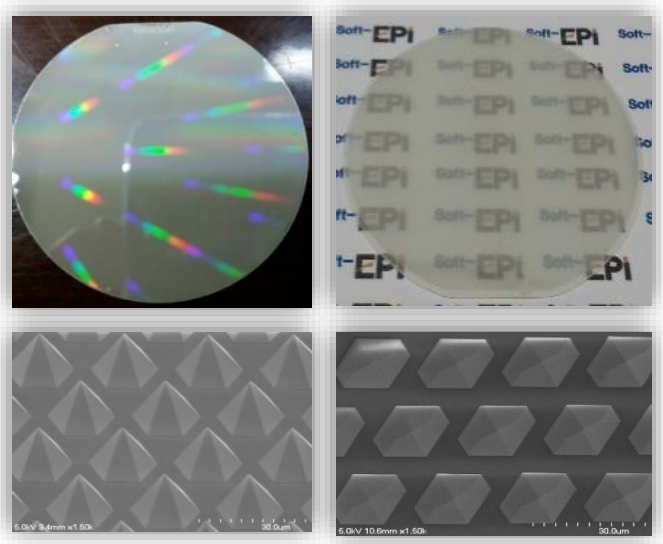
Hwaseong-si, Gyeonggi-do, South Korea

https://www.soft-epi.com/



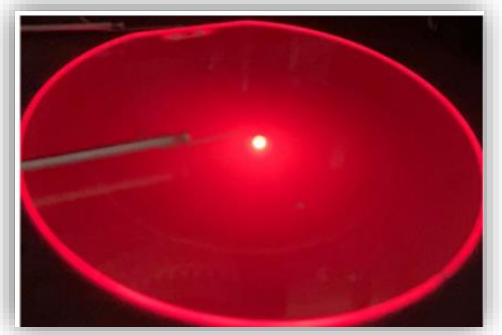
GaN Templates & LED Wafers

- *GaN Templates*
- *UV-LED epi wafers*
- *Selective Area Epitaxy*



Epitaxy for micro-LEDs

- *InGaN based red LED epi wafers*



- *GaN-based monolithic RGB LED epi wafers*

Contents

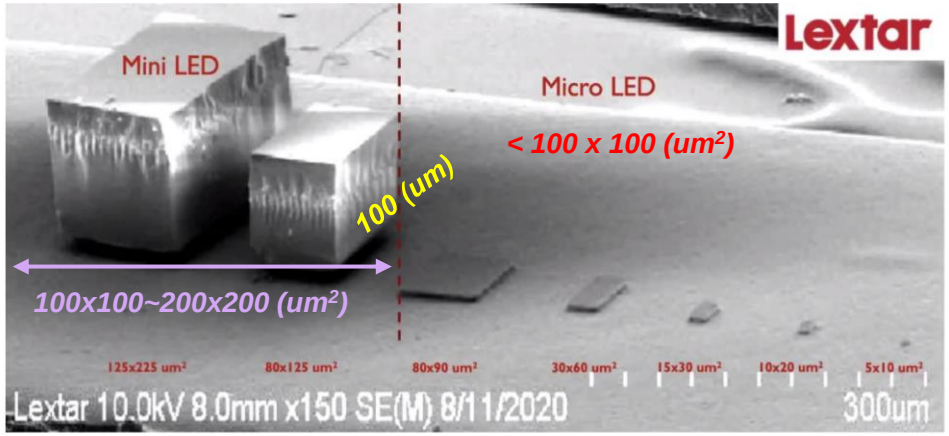
1. Introduction

What is Micro-LED for Display?

LEDs with a size below 100 μm are called "Micro-LEDs"

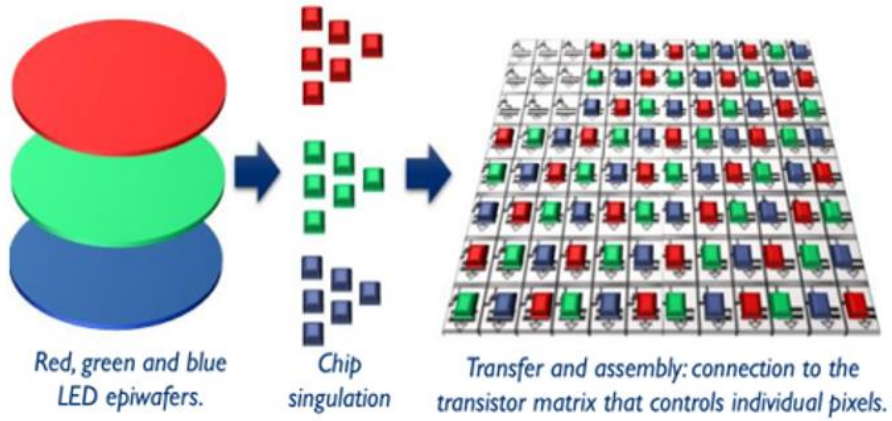
- ***Sub-pixels in Micro-LED displays.***
- ***Require high processing temperatures of over 1000℃.***
- ***Difficult to grow and pattern directly on backplane for display.***
- ***Require complex manufacturing processes.***
  (Epi-wafer → Chip Singulation → Chip transfer & bonding)

Mini-LEDs and Micro-LEDs



– This image from Lextar clearly shows the difference between mini- and Micro-LEDs. It is not about size difference only but also the thickness (if substrate is included or not)

**Referenced from* IDTechEx *2021*



MicroLED display assembled from red, green and blue LED chips.

**Referenced from 2019 Yole Development*

Advantages of Micro-LED Display

- ***Low power consumption***

  = Long Battery life

- ***Perfect black + very high brightness***
- ***High Resolution/Pixel density***
- ***Fast refresh rates***
- ***Wide viewing angles***
- ***Curved/flexible Display***
- ***Long lifetime, environmental stability***

Micro-LED Applications

Micro LED issues

- ***Blue and Green LEDs have similar structures, materials and manufacturing processes, but Red LEDs are completely different.***

- ***Some issues may arise when driving RGB display devices.***

Epi wafer for blue and green LEDs

- ***AlGaInP Red LED Issue***

- *Conventional red LEDs have different driving voltages due to the use of a different material (AlGaInP) than the green/blue LED (InGaN).*
- *Poor red LED yield. AlGaInP material is brittle and the chip transfer yield is poor.*
- *The manufacturing process of red LED is complicated. Substrate removal and substrate replacement are required. Manufacturing cost rises.*

Epi wafer for red LED

→ ***GaN based red LED required***

**Referenced from Micro-LED Displays 2021-2031; IDTechEx*

Micro LED issues

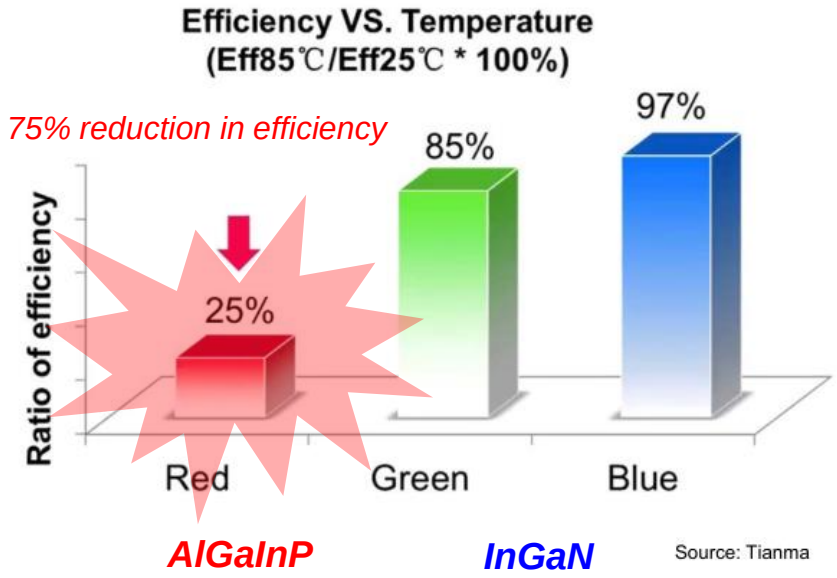
◆ ***Micro LED efficiency is affected by current density and temperature.***

*** InGaN based LED**

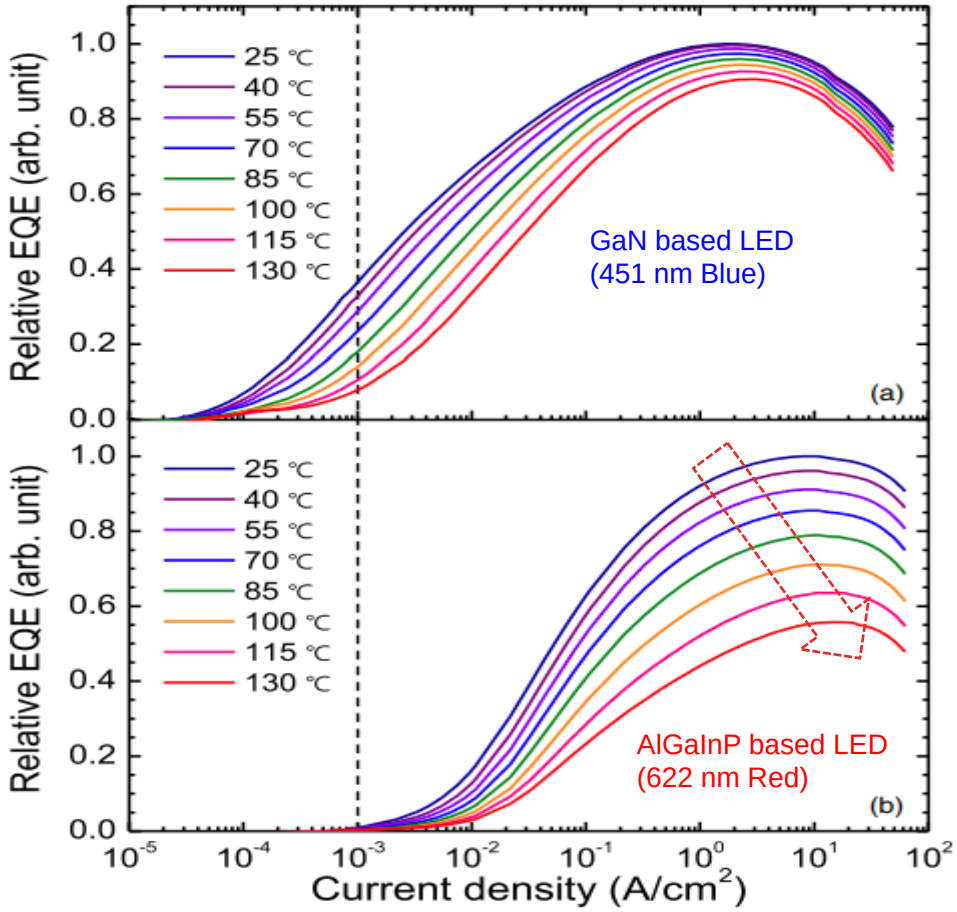
- ***J-Droop****: the efficiency droop with increasing current density*

*** AlGaInP based LED**

- ***T-Droop*** *: the efficiency droop with increasing temperature*



Jpn. J. Appl. Phys. 58, SCCC08 (2019)

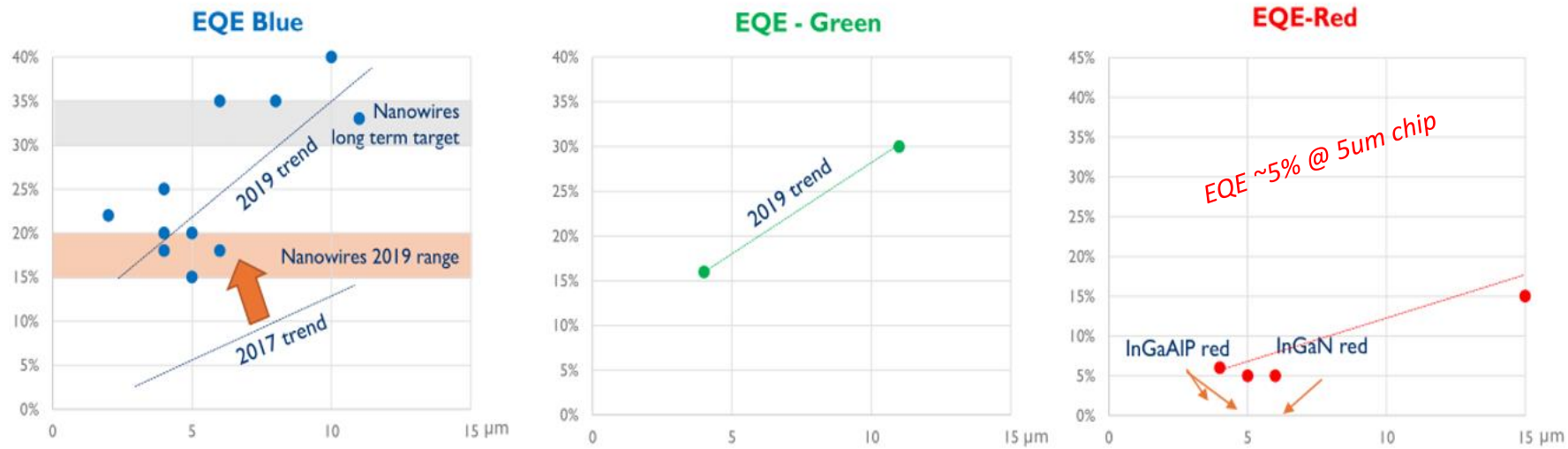


Relative EQE versus current density for (a) blue and (b) red LED samples.

Micro LED issues

◆ *EQE vs. Chip Size*

- *The smaller the chip size, the lower the external quantum efficiency (EQE).*
- *The EQE of red LEDs is relatively lower compared to other green and blue LEDs.*
- *The AlGaInP material system is more sensitive to chip size. It has been reported that high surface recombination rates reduce efficiency.*
- *There have been attempts to replace AlGaInP with GaN for red micro-LEDs.*
- *Although the efficiency of GaN-based red LEDs is low at present, performance is expected to gradually improve.*



** Referenced from 2019 Yole Development*

** Typical external quantum efficiency(EQE) of traditional LEDs with chip size.*

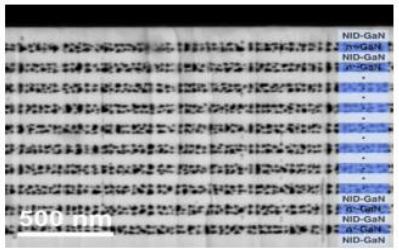
2. GaN based Red LEDs

Technology trend of GaN red LEDs

◆ Various attempts to create GaN-based red LEDs

Manufacturing process

POROTECH



- **Multi-layered porous template**

Complex manufacturing process, high manufacturing cost

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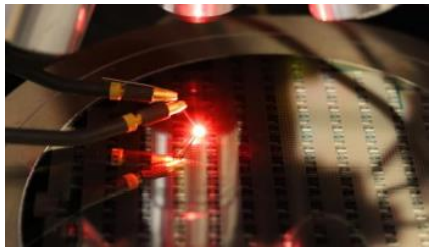
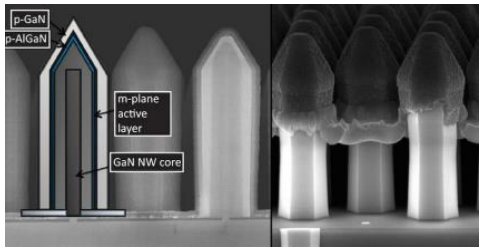


- **GaN on Silicon method**

Additional process required to remove silicon to prevent light absorption

glō



- **Nanowire method**

Mass production yield is low since the process is complicated.

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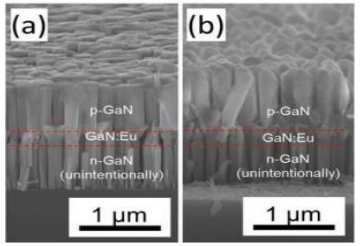
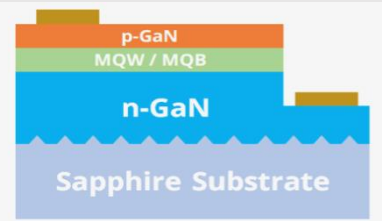


- **Doping method**

Limited performance improvement due to the method of doping Eu element

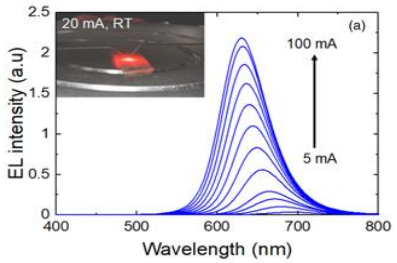
Soft-EPi



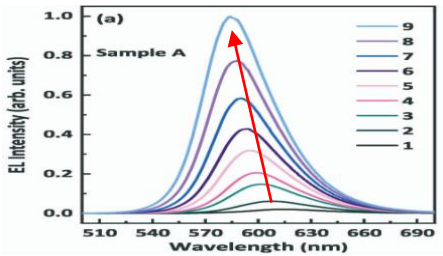
- GaN/Sapphire structure
- ***Same as existing B/G epi growth method. Simple manufacturing process.***

Characteristics

The Japan Society of Applied Physics [2]



OSA Publishing [3]



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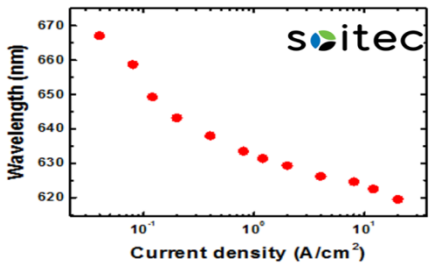
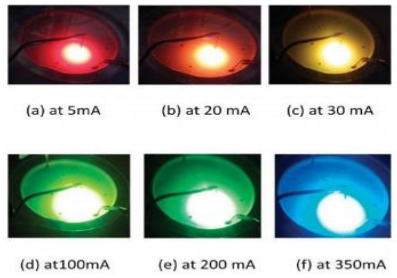


Ostendo

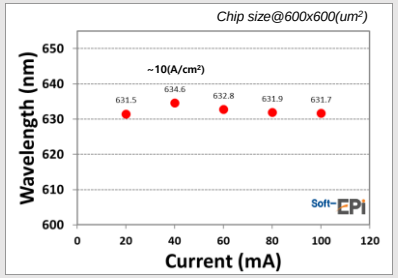


- **Wavelength change of GaN-based Red LED according to injecting current**

In the case of InGaN-based Red LED, there is a significant change in wavelength depending on the current density, which causes problems for displays.

- **Color change according to the amount of current**

<u>If the current increases, the wavelength becomes shorter, so red cannot be realized.</u>



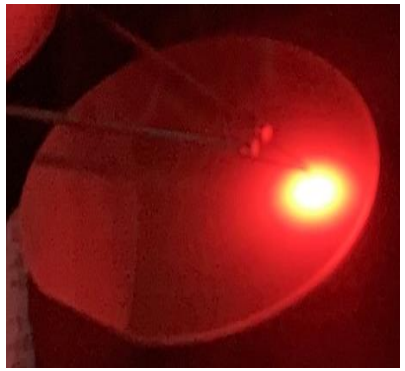
- ***Almost no change in wavelength according to injecting current***
- **Stable over a wide temperature range (GaN based)**

SOFT-EPI's InGaN based RED LEDs

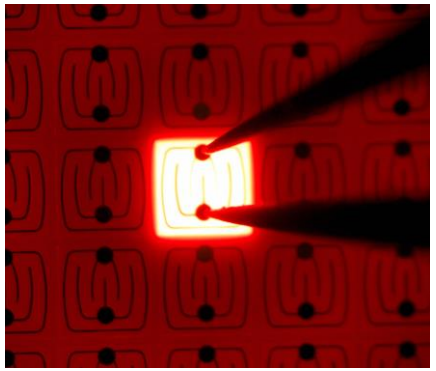
◆ Successfully developed GaN-based RED LED for the first time in Korea.

SOFT-EPI's InGaN red LED epi wafers

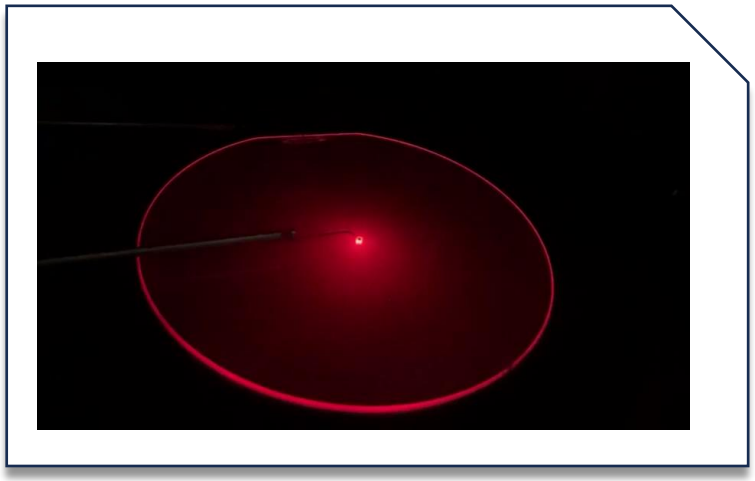
- *Similar to GaN epitaxial growth technology for growing blue LED epi.*
- ***No new facility investment is required for red LED.*** *(AlGaInP LED requires separate GaAs epitaxial MOCVD)*
- *Almost no change in wavelength with injection current density.*



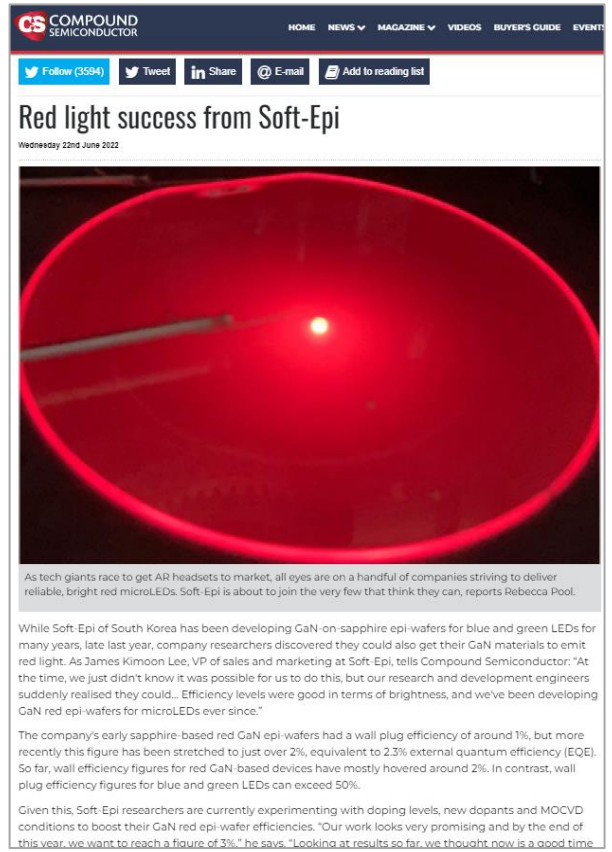
Red emission image of GaN-based epitaxial wafer grown on PSS (pattered Sapphire Substrate)



Red emission image of GaN-based LED chip (Lateral Chip 600um x600um)



Video of GaN-based LED emitting red light
Epitaxial wafer grown on DSP sapphire substrate



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Red light success from Soft-Epi

Wednesday 22nd June 2022

As tech giants race to get AR headsets to market, all eyes are on a handful of companies striving to deliver reliable, bright red microLEDs. Soft-Epi is about to join the very few that think they can, reports Rebecca Pool.

While Soft-Epi of South Korea has been developing GaN-on-sapphire epi-wafers for blue and green LEDs for many years, late last year, company researchers discovered they could also get their GaN materials to emit red light. As James Kimoon Lee, VP of sales and marketing at Soft-Epi, tells Compound Semiconductor: "At the time, we just didn't know it was possible for us to do this, but our research and development engineers suddenly realised they could... Efficiency levels were good in terms of brightness, and we've been developing GaN red epi-wafers for microLEDs ever since."

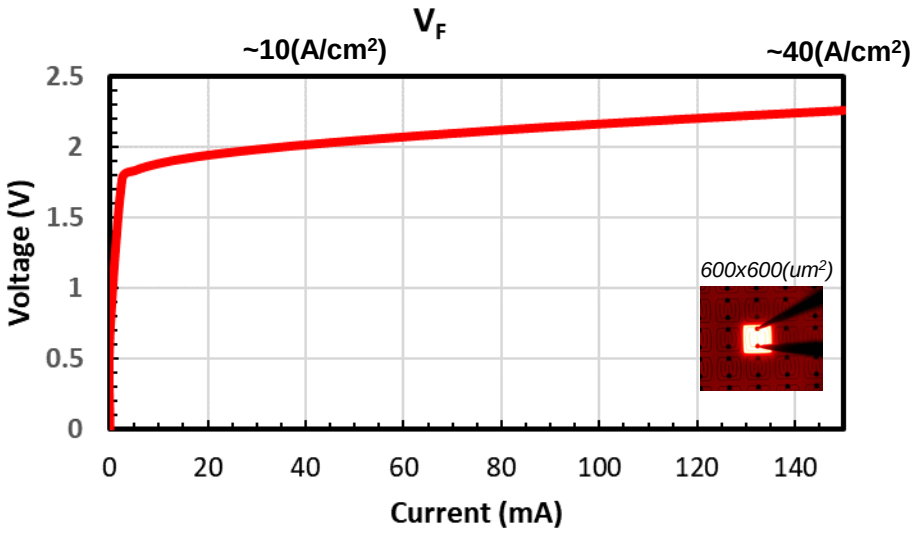
The company's early sapphire-based red GaN epi-wafers had a wall plug efficiency of around 1%, but more recently this figure has been stretched to just over 2%, equivalent to 2.3% external quantum efficiency (EQE). So far, wall efficiency figures for red GaN-based devices have mostly hovered around 2%. In contrast, wall plug efficiency figures for blue and green LEDs can exceed 50%.

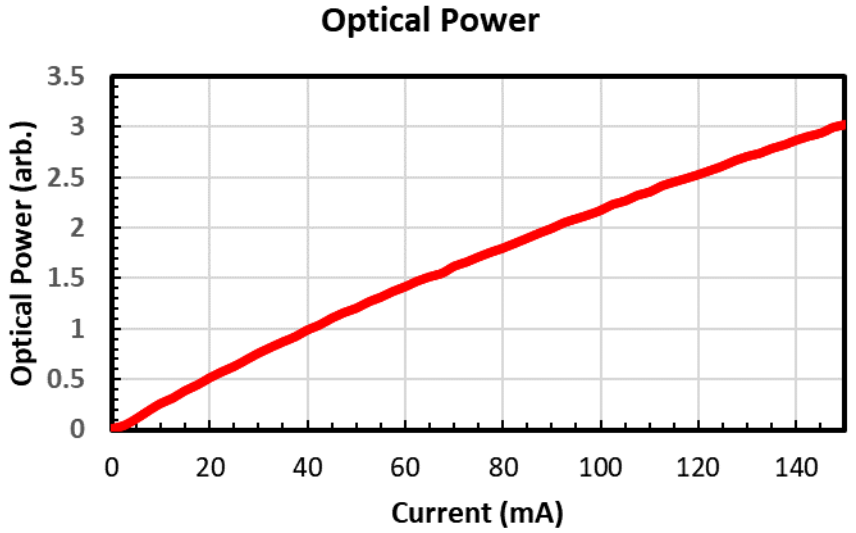
Given this, Soft-Epi researchers are currently experimenting with doping levels, new dopants and MOCVD conditions to boost their GaN red epi-wafer efficiencies. "Our work looks very promising and by the end of this year, we want to reach a figure of 3%," he says. "Looking at results so far, we thought now is a good time

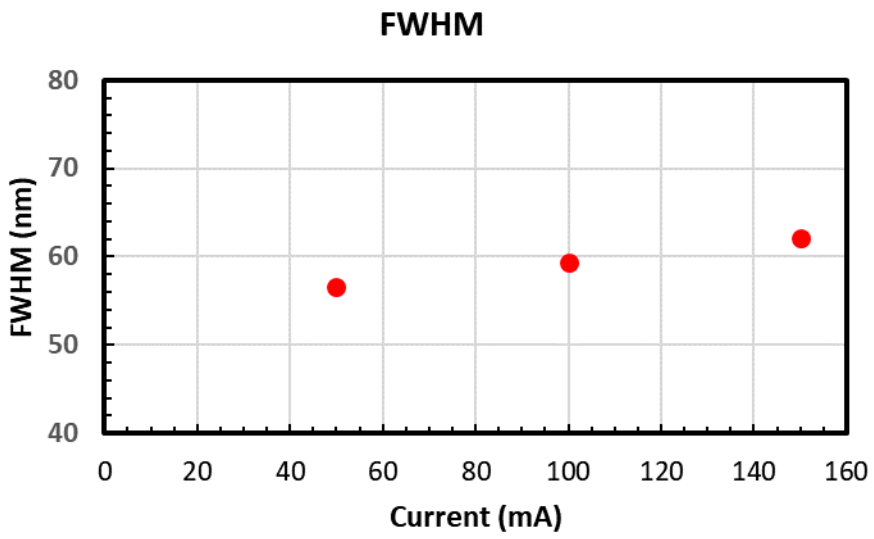
*Related articles

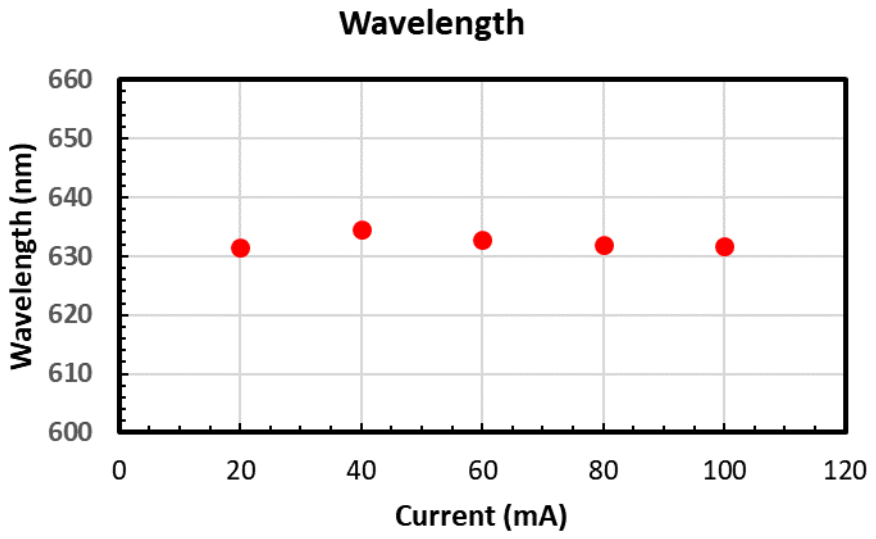
- https://compoundsemiconductor.net/article/114788/Soft-Epi_to_ship_GaN_red_epi_wafers_for_Micro_LEDs
- https://compoundsemiconductor.net/article/114965/Red_light_success_from_Soft-Epi
- https://english.etnews.com/20210518200002

Characteristics of Soft-Epi's InGaN Red LED







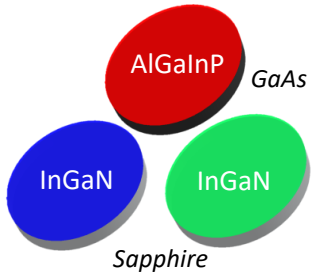


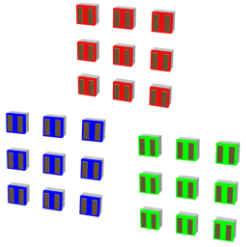
3. GaN based Monolithic RGB LEDs

Technology trend of Monolithic LEDs

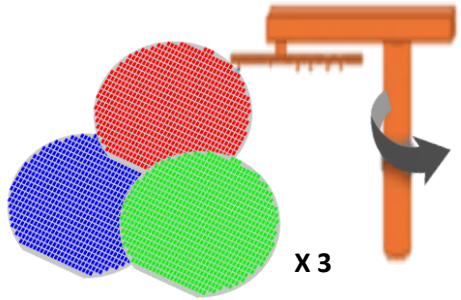
Conventional RGB LED array in Micro-LED Display

- ***Individual R,G,B Epi wafer***

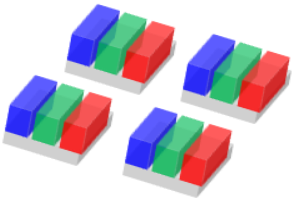




Difficult



Laterally arranged RGB LED chips

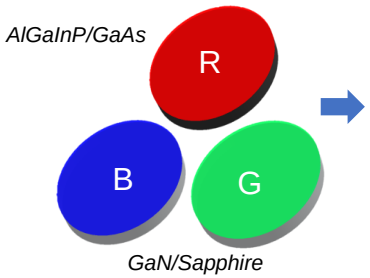


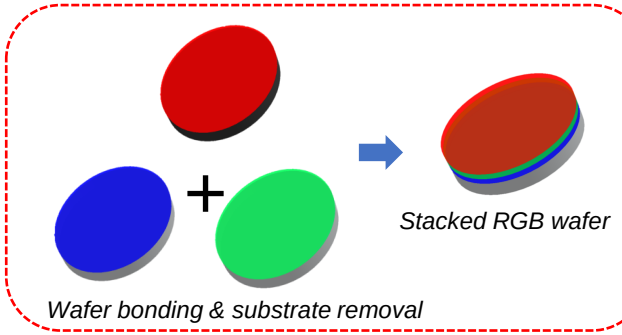
3-Epitaxy (R/G/B) → 3-Chip Manufacturing → 3- Chip Transferring → Final Pixel

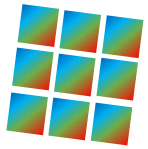
Monolithic RGB LED with wafer bonding

Example of monolithic RGB LED

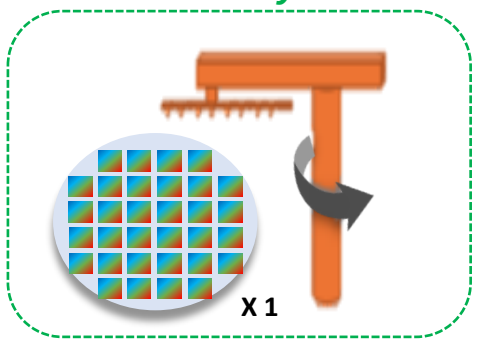
- ***Stacked RGB Epi layer with wafer bonding***

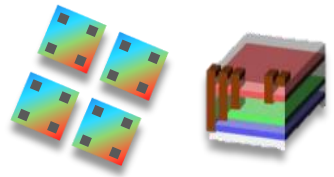






Easy





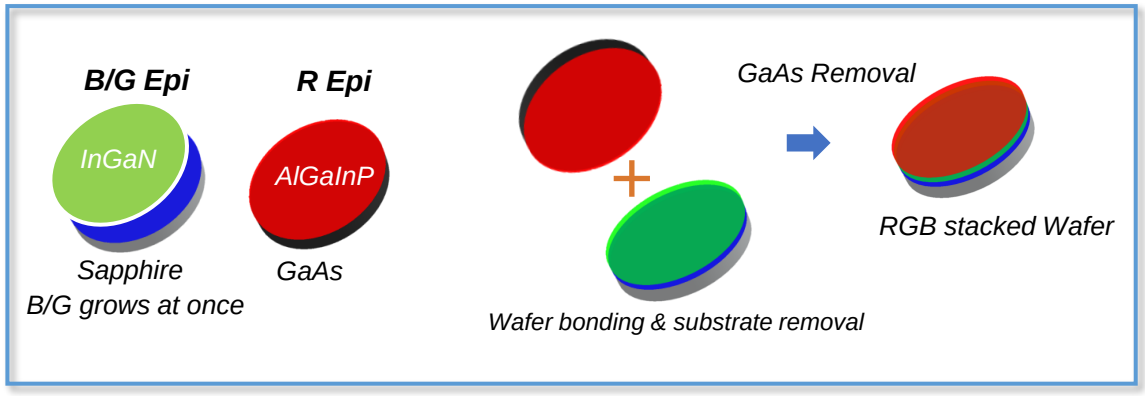
3-Epitaxy(R/G/B) → 2-Wafer Bonding → 1-Chip Manufacturing → 1- Chip Transferring → Final Pixel

Technology trend of Monolithic LEDs

Vertically stacked Monolithic RGB LED

Epi layer or chip bonding is required.

1. Wafer Bonding



2. RGB LED Chip bonding with adhesive

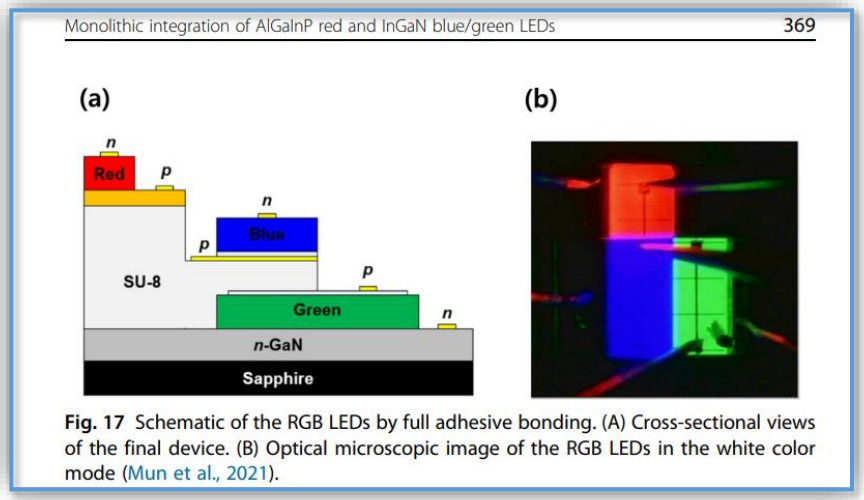
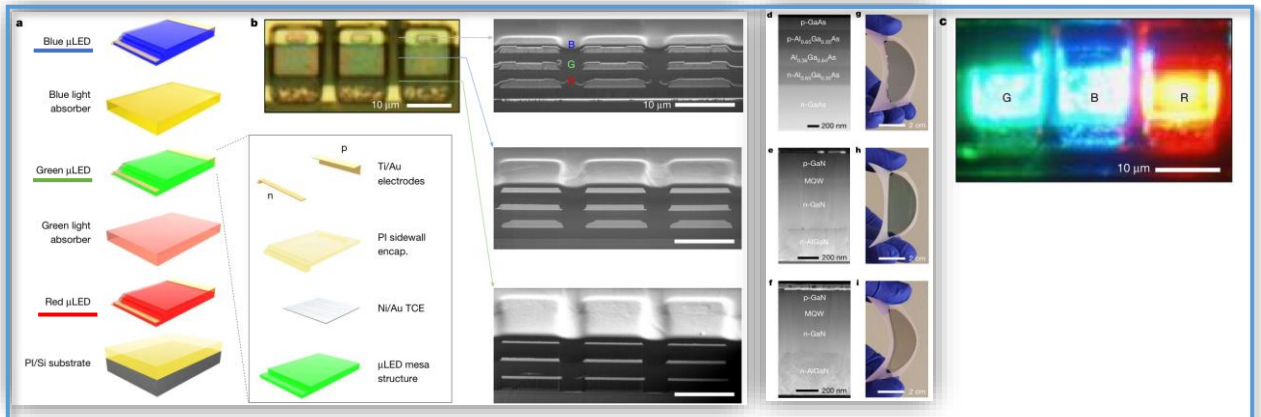


Fig. 17 Schematic of the RGB LEDs by full adhesive bonding. (A) Cross-sectional views of the final device. (B) Optical microscopic image of the RGB LEDs in the white color mode (Mun et al., 2021).

** Semiconductors and Semimetals, Volume 106, 2021, Pages 345-387*

3. Epi layer transfer (MIT)



A Vertical full-colour micro-LEDs via 2D materials-based layer transfer ; [Nature](#) ***volume 614***, *pages81–87 (2023)*

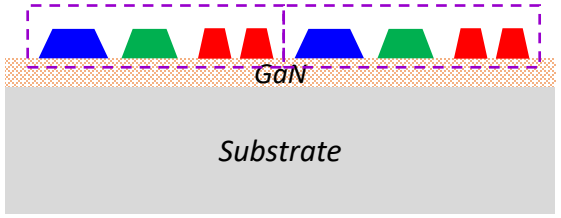
- *2D materials based layer transfer (2DLT) technique*
- *Epitaxy of red AlGaAs LED on graphene-coated GaAs substrate*
- *Epitaxy of blue and green InGaN LED on hBN-coated sapphire substrate*
- *Epi layer transfer using thermal release tape (TRT)*

SOFT-EPI's Monolithic RGB LED Technology

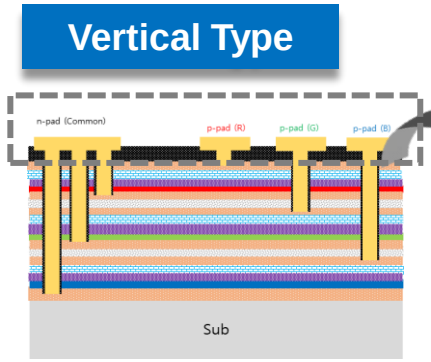
GaN based monolithic RGB LED

Lateral Type

1 time RGB Growth

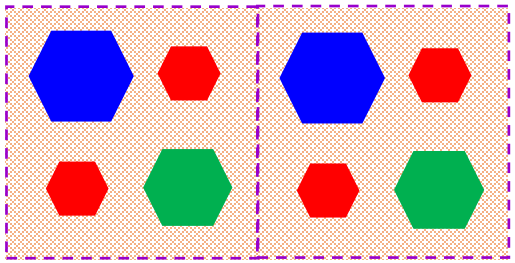


Vertical Type



p-pad (R) p-pad (G)

n-pad (Common) p-pad (B)

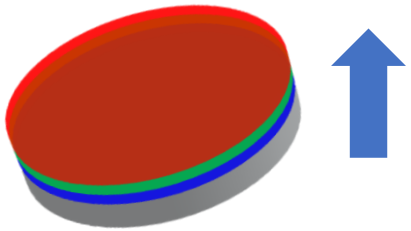


Selective Area Growth (SAG) at one time

RGB LEDs are grown at once.

No Wafer Bonding

All RGB LEDs are made of GaN material.



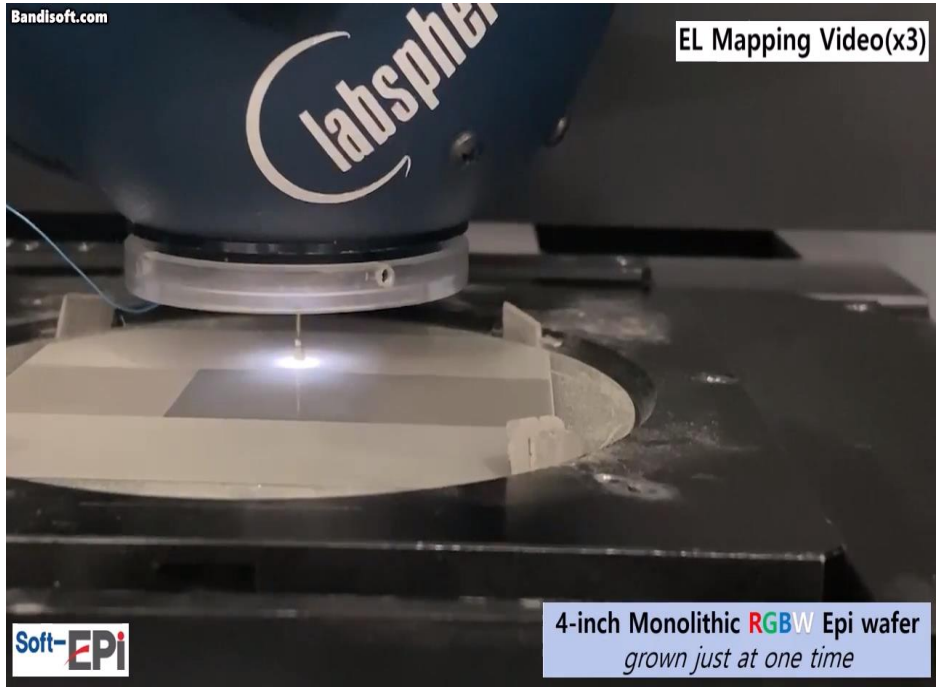
1 time RGB Epitaxy

SOFT-EPI's Monolithic RGB LEDs; Lateral type

Lateral Type of Monolithic RGB

Lateral Type of RGB

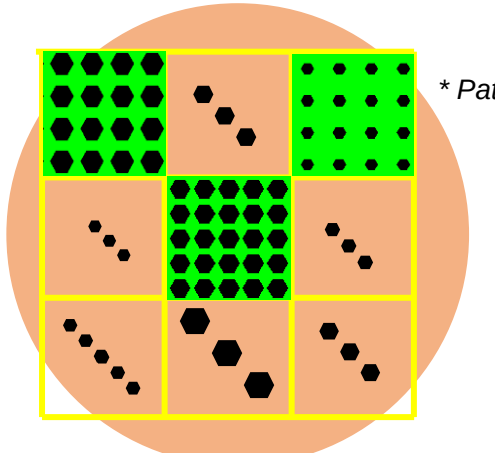
1 time RGB layer growth



Measured on a wafer with a EL Prober

- *Multiple colors come out of a single wafer.*

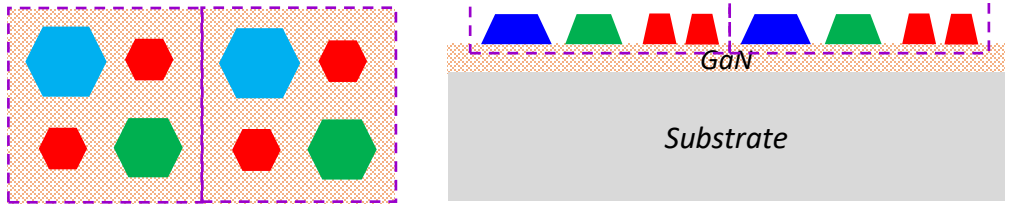
Each of the 9 blocks has a different sized LED array.



** Pattern is an example.*

Selective Area Growth (SAG) at one time

Example of RGB pixel

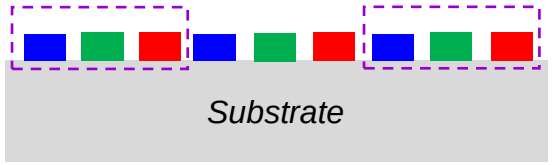


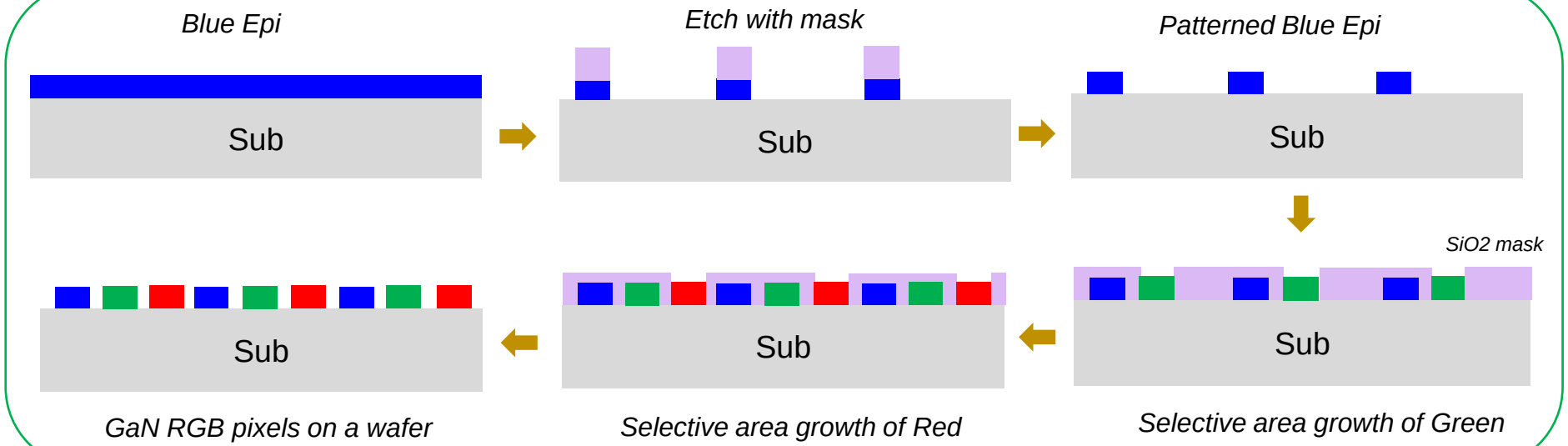
Using this technology, it is possible to make RGB LEDs into one pixel on a single wafer.

SOFT-EPI's Monolithic RGB LEDs; Lateral type

InGaN based RGB Epitaxy

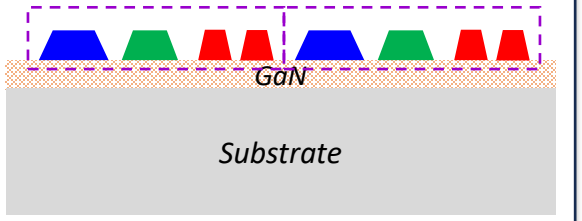
Lateral type of RGB (I)

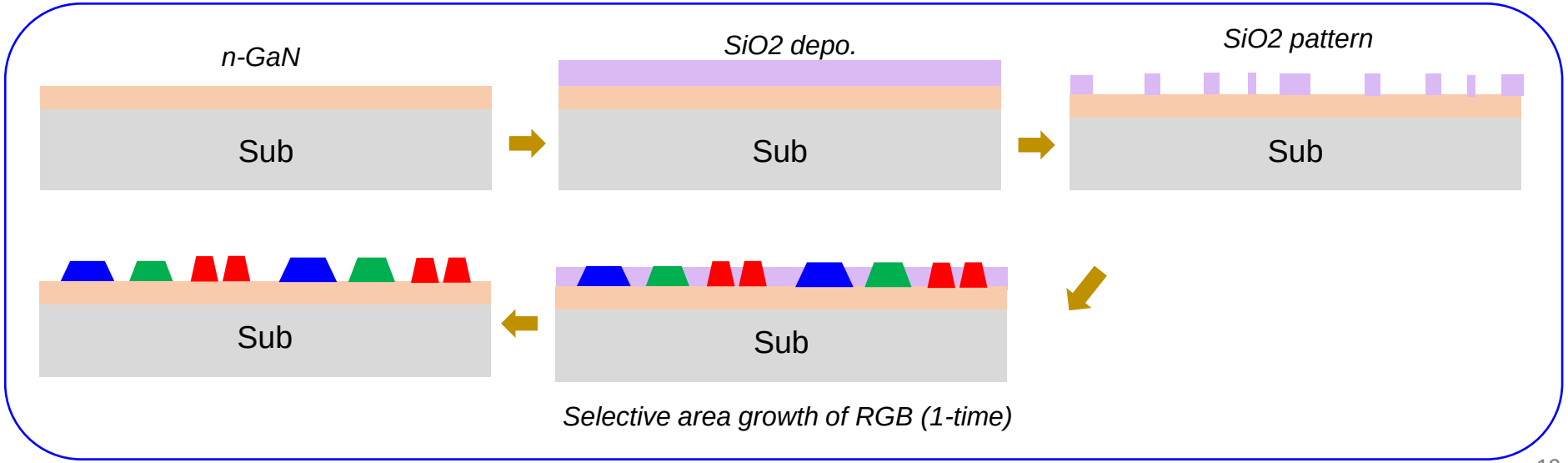




Lateral type of RGB (II)

1-time selective area growth



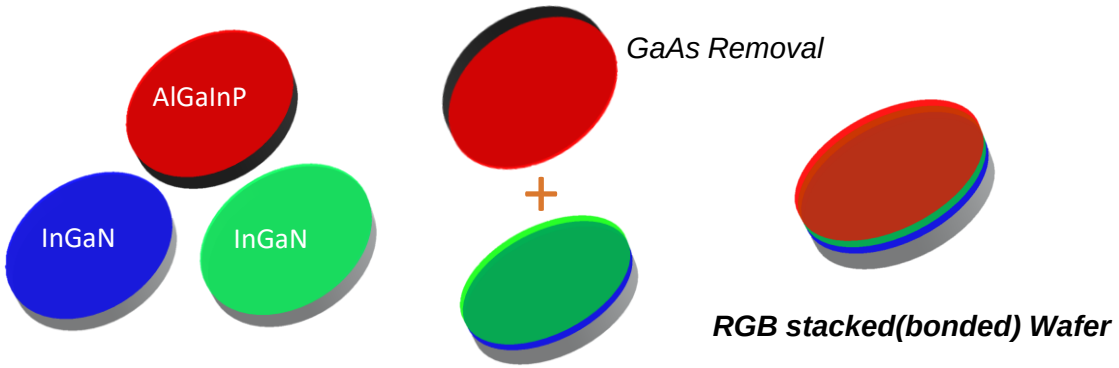


SOFT-EPI's Monolithic RGB LEDs; Vertical type

Vertical Type of Monolithic RGB

No Wafer Bonding Type

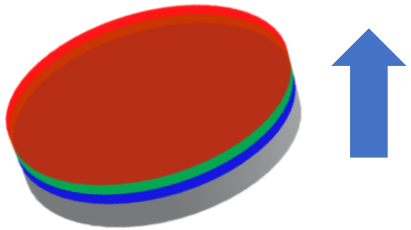
Conventional stacked(bonded) Monolithic RGB LED



RGB stacked(bonded) Wafer

Soft-Epi's Vertically grown monolithic RGB LED

***No Wafer Bonding** in Manufacturing Process*



1 time RGB Epitaxy

Ultimate Technology for Micro LED

Bonded Type of RGB monolithic LED

- Wafer bonding or layer transfer required → complex process
- Relatively low yield ; Resin(adhesive) bonding
- InGaN and AlGaInP layer are used.

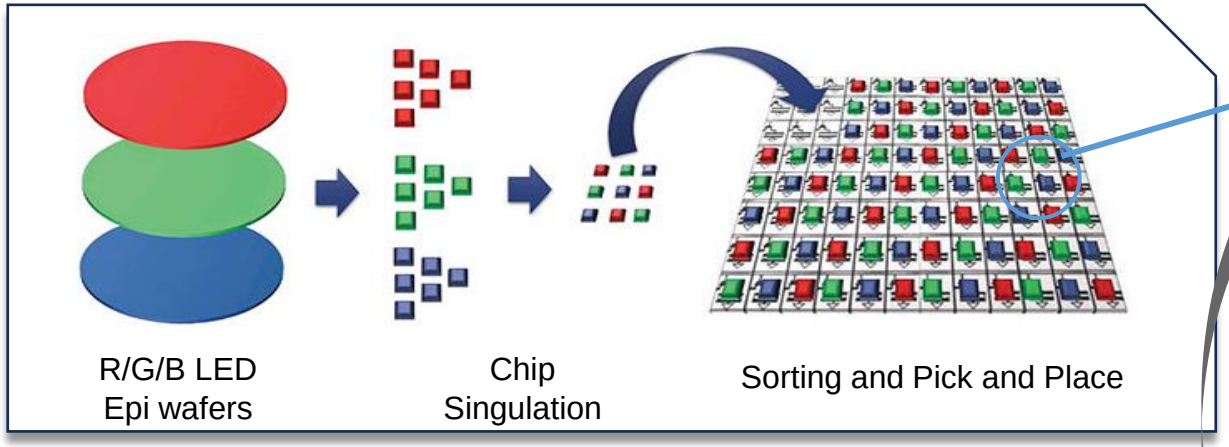
Vertically grown RGB monolithic LED

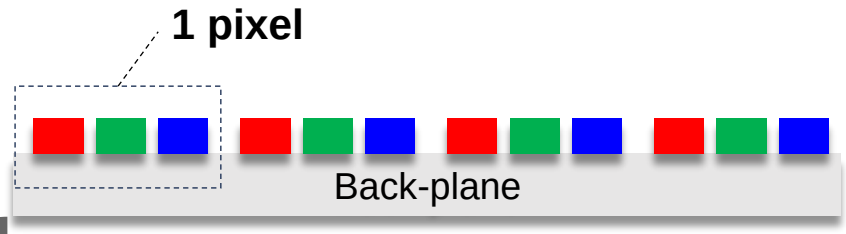
- No need 'R+G+B wafer bonding' → simple process
- High yield ; no need resin(glue)
- Only InGaN layer is used.

SOFT-EPI's Monolithic RGB LEDs; Vertical type

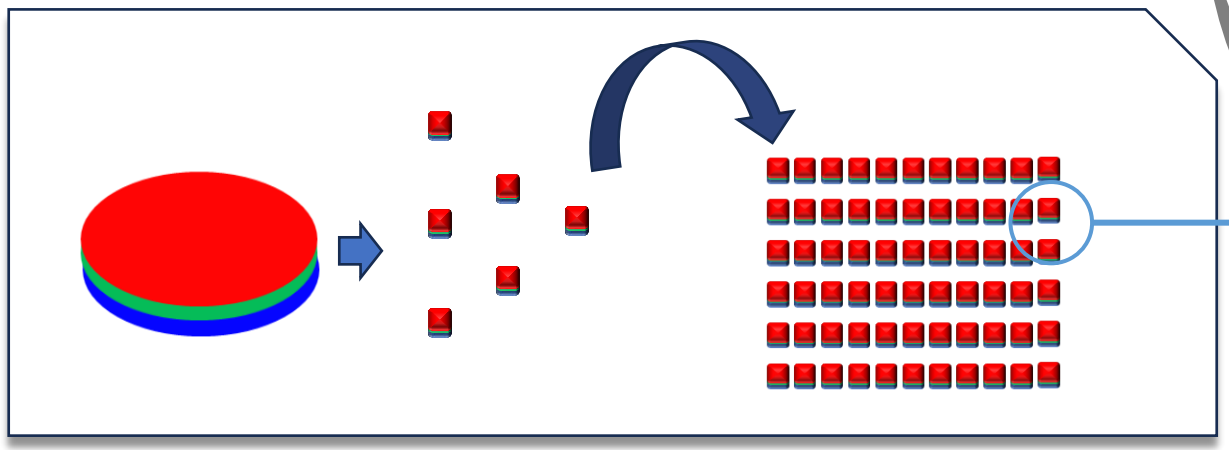
Advantages of Vertical type Monolithic LEDs

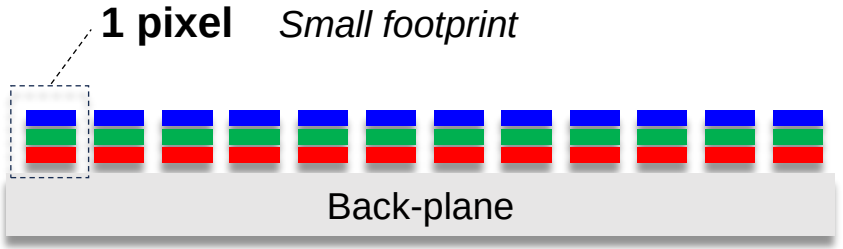
- **Conventional type**





- **Monolithic type**





Compared to Conventional type

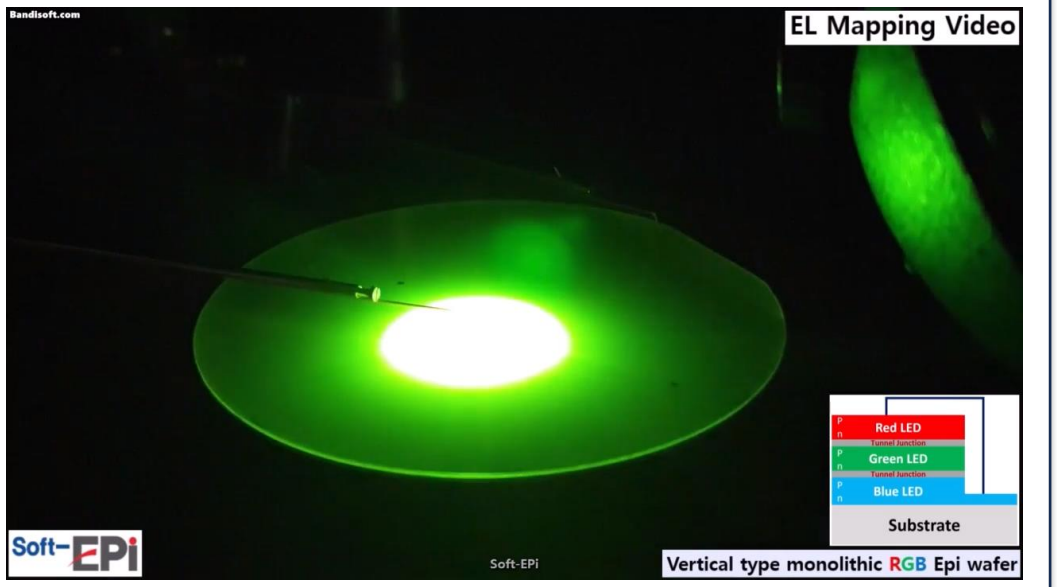
- **# of chip transfer can be reduced by 1/3.**
- **# of chips required for the display is reduced by 1/3.**
- **Pixel size can be smaller. Higher resolutions are possible.**

Advantages of high resolution

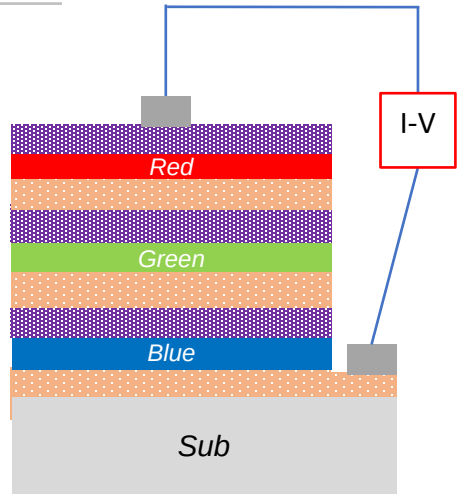
SOFT-EPI's Monolithic RGB LEDs; Vertical type

Soft-Epi's first monolithic RGB wafer sample

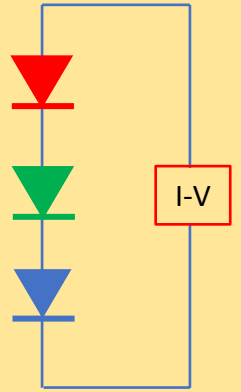
RGB Epi simply designed for quick check



Light emission video of monolithic RGB wafer with increasing current

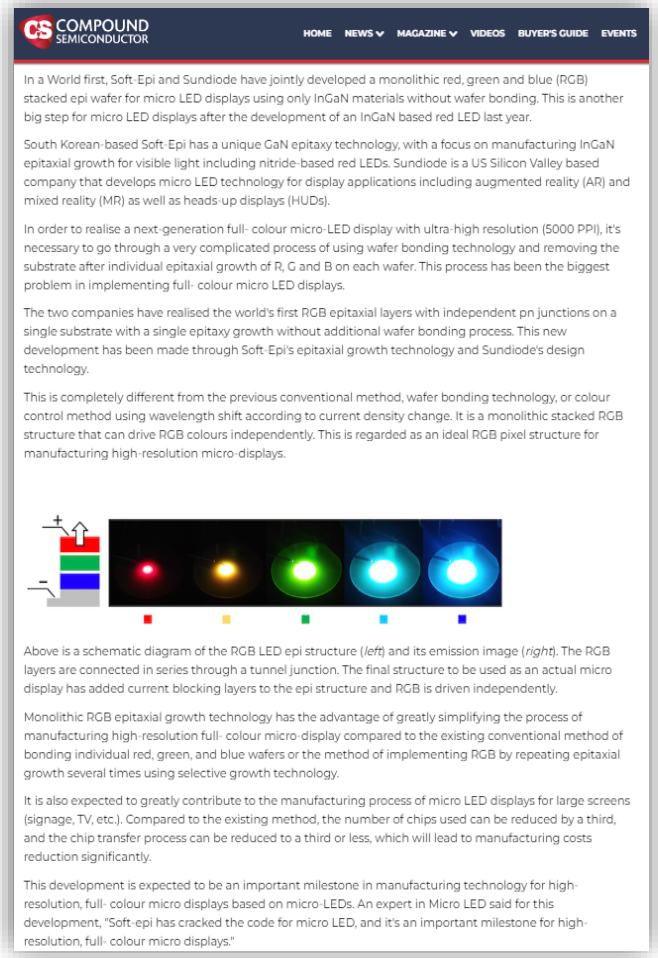


- *Low Vt*
- *Low Efficiency*



- *High Vt*
- *High Efficiency*

Vt: Turn-on voltage



COMPOUND SEMICONDUCTOR

HOME NEWS MAGAZINE VIDEOS BUYER'S GUIDE EVENTS

In a World first, Soft-Epi and Sundiode have jointly developed a monolithic red, green and blue (RGB) stacked epi wafer for micro LED displays using only InGaN materials without wafer bonding. This is another big step for micro LED displays after the development of an InGaN based red LED last year.

South Korean-based Soft-Epi has a unique GaN epitaxy technology, with a focus on manufacturing InGaN epitaxial growth for visible light including nitride-based red LEDs. Sundiode is a US Silicon Valley based company that develops micro LED technology for display applications including augmented reality (AR) and mixed reality (MR) as well as heads-up displays (HUDs).

In order to realise a next-generation full- colour micro-LED display with ultra-high resolution (5000 PPI), it's necessary to go through a very complicated process of using wafer bonding technology and removing the substrate after individual epitaxial growth of R, G and B on each wafer. This process has been the biggest problem in implementing full- colour micro LED displays.

The two companies have realised the world's first RGB epitaxial layers with independent pn junctions on a single substrate with a single epitaxy growth without additional wafer bonding process. This new development has been made through Soft-Epi's epitaxial growth technology and Sundiode's design technology.

This is completely different from the previous conventional method, wafer bonding technology, or colour control method using wavelength shift according to current density change. It is a monolithic stacked RGB structure that can drive RGB colours independently. This is regarded as an ideal RGB pixel structure for manufacturing high-resolution micro-displays.

Above is a schematic diagram of the RGB LED epi structure (*left*) and its emission image (*right*). The RGB layers are connected in series through a tunnel junction. The final structure to be used as an actual micro display has added current blocking layers to the epi structure and RGB is driven independently.

Monolithic RGB epitaxial growth technology has the advantage of greatly simplifying the process of manufacturing high-resolution full- colour micro-display compared to the existing conventional method of bonding individual red, green, and blue wafers or the method of implementing RGB by repeating epitaxial growth several times using selective growth technology.

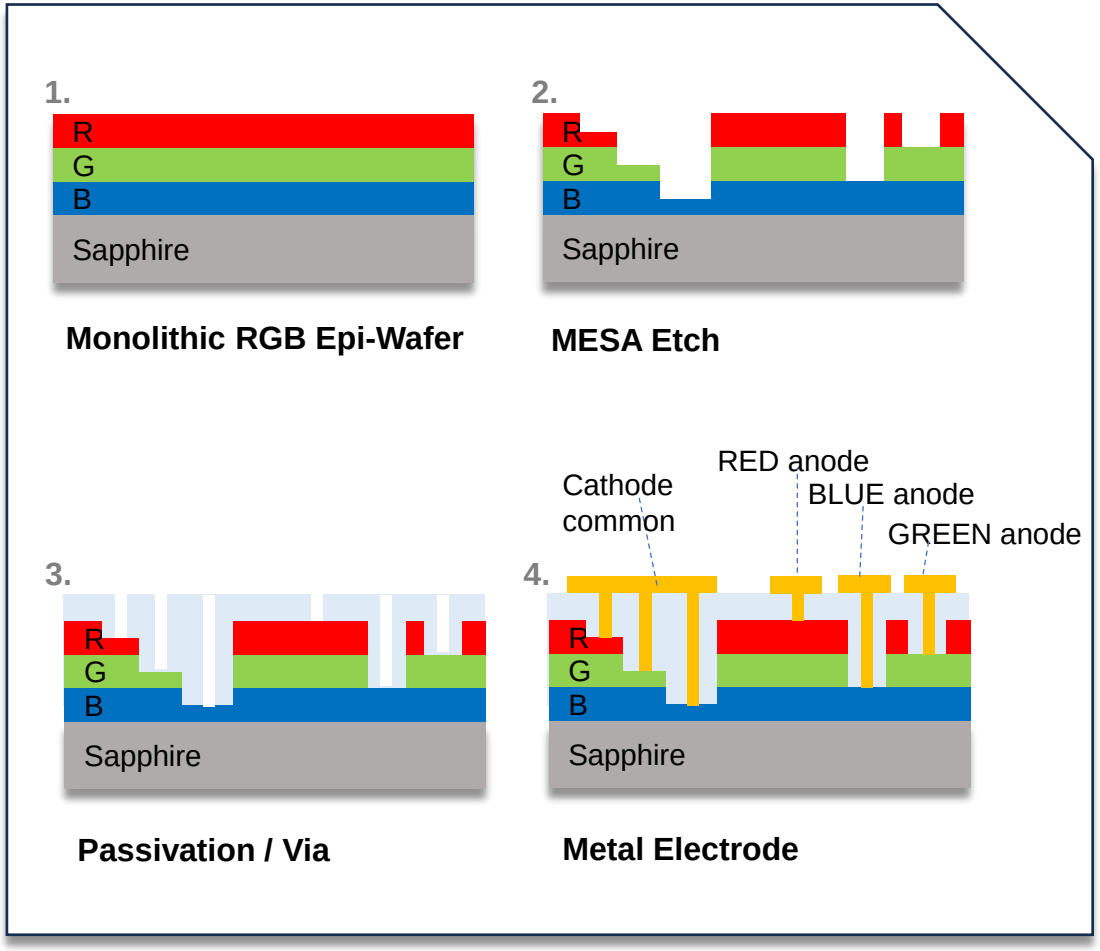
It is also expected to greatly contribute to the manufacturing process of micro LED displays for large screens (signage, TV, etc.). Compared to the existing method, the number of chips used can be reduced by a third, and the chip transfer process can be reduced to a third or less, which will lead to manufacturing costs reduction significantly.

This development is expected to be an important milestone in manufacturing technology for high-resolution, full- colour micro displays based on micro-LEDs. An expert in Micro LED said for this development, "Soft-epi has cracked the code for micro LED, and it's an important milestone for high-resolution, full- colour micro displays."

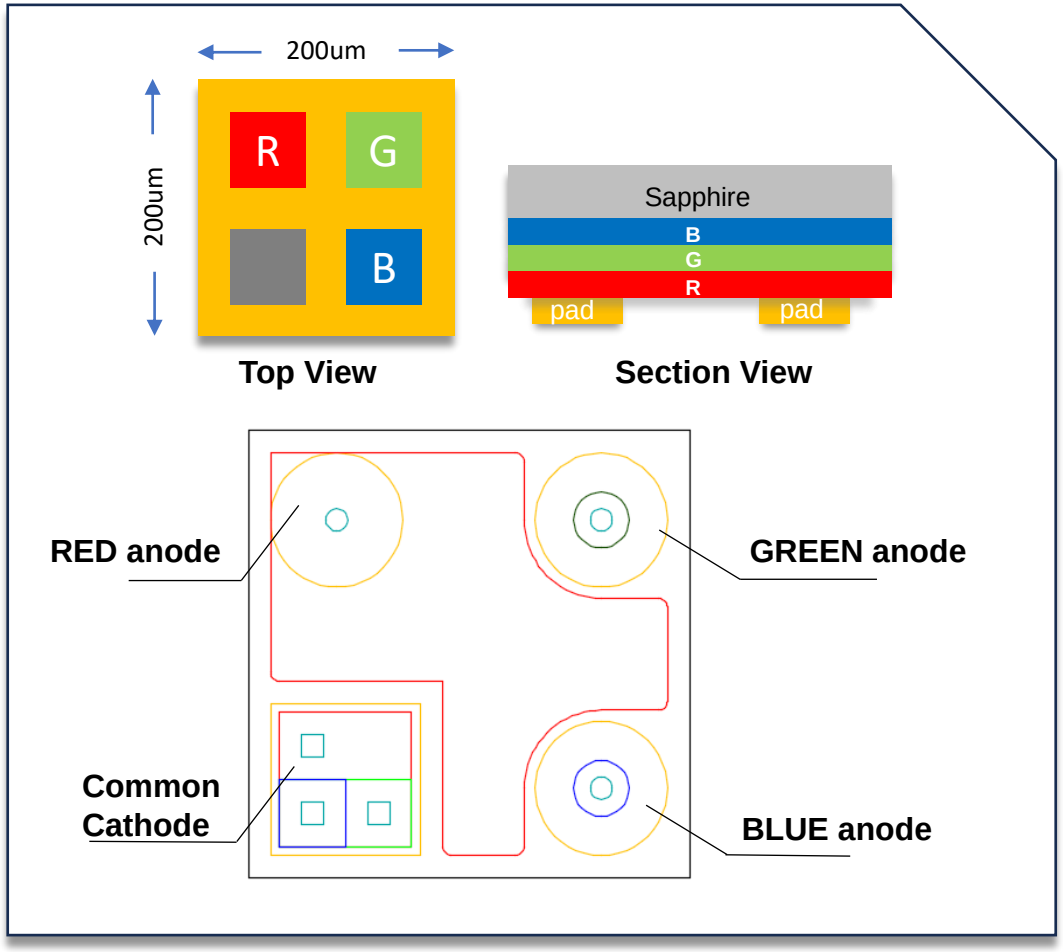
January 2023

Monolithic RGB LED Chip (4-pad design)

Process Design



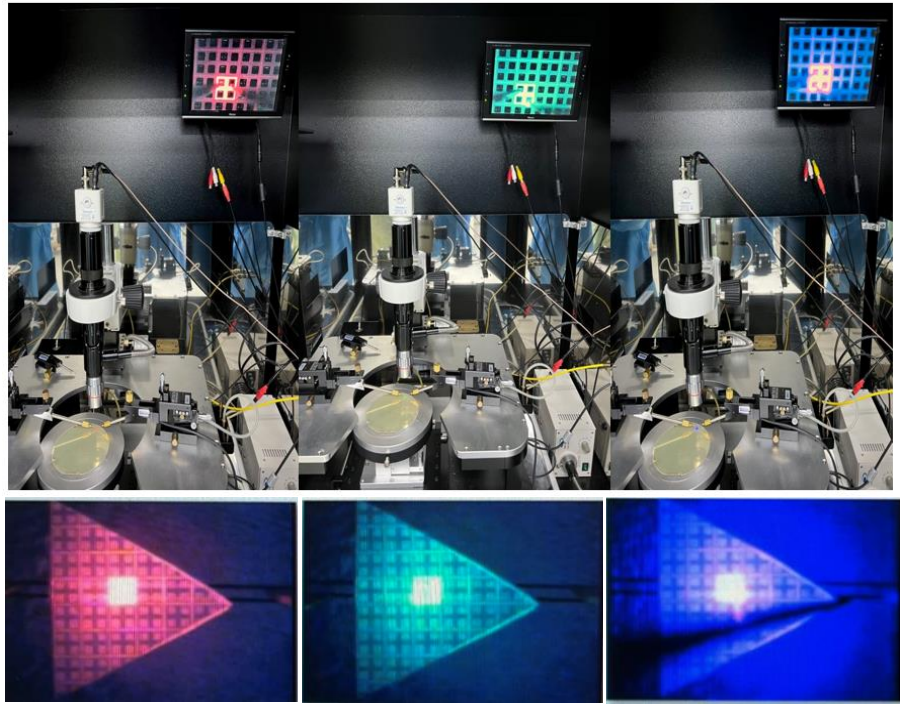
Chip Design



Monolithic RGB LED Chip (4-pad design)

Driving Image

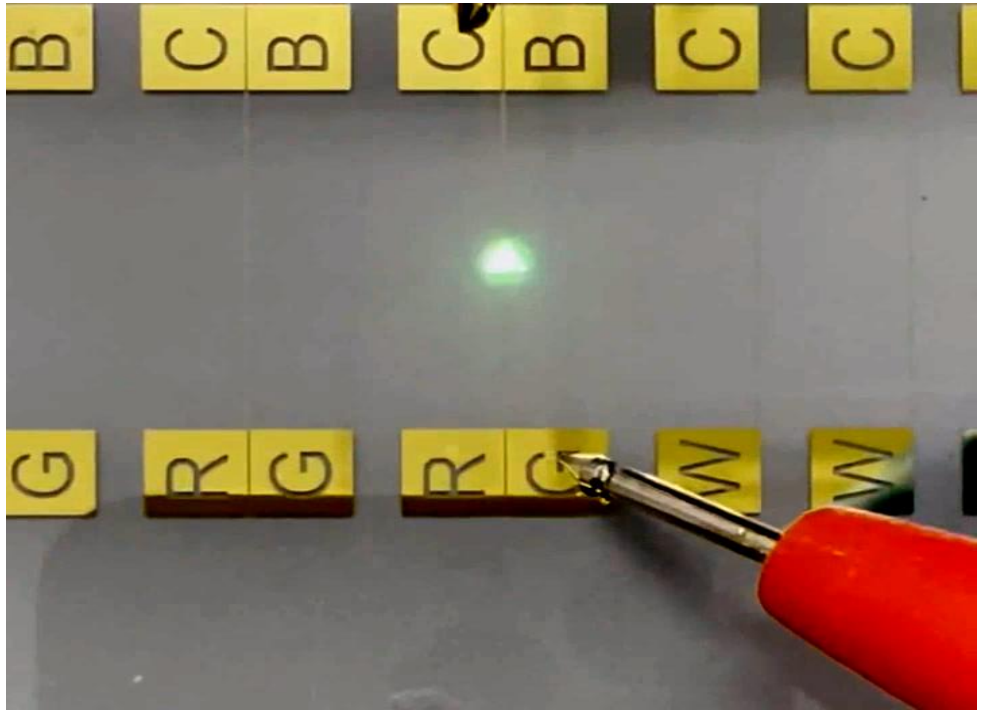
Chip process is performed by Lumens.



Chip size : 200(um) x 200(um)

Driving Video

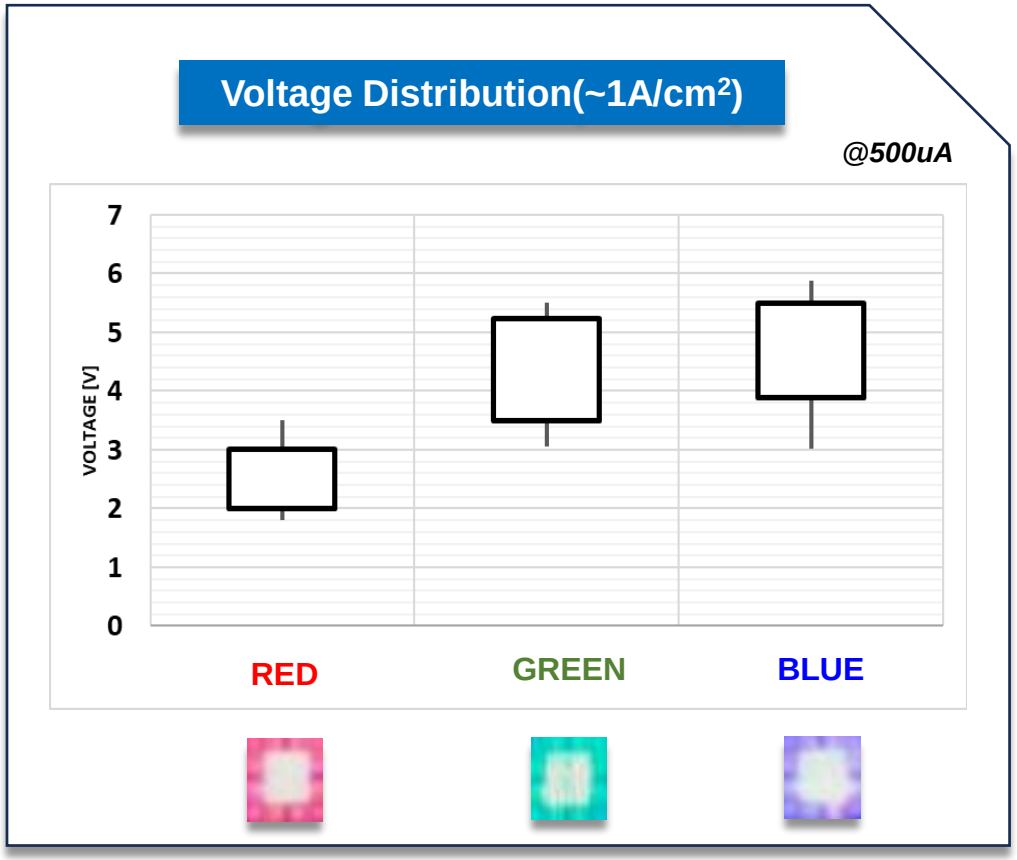
One chip are mounted on a printed circuit substrate.

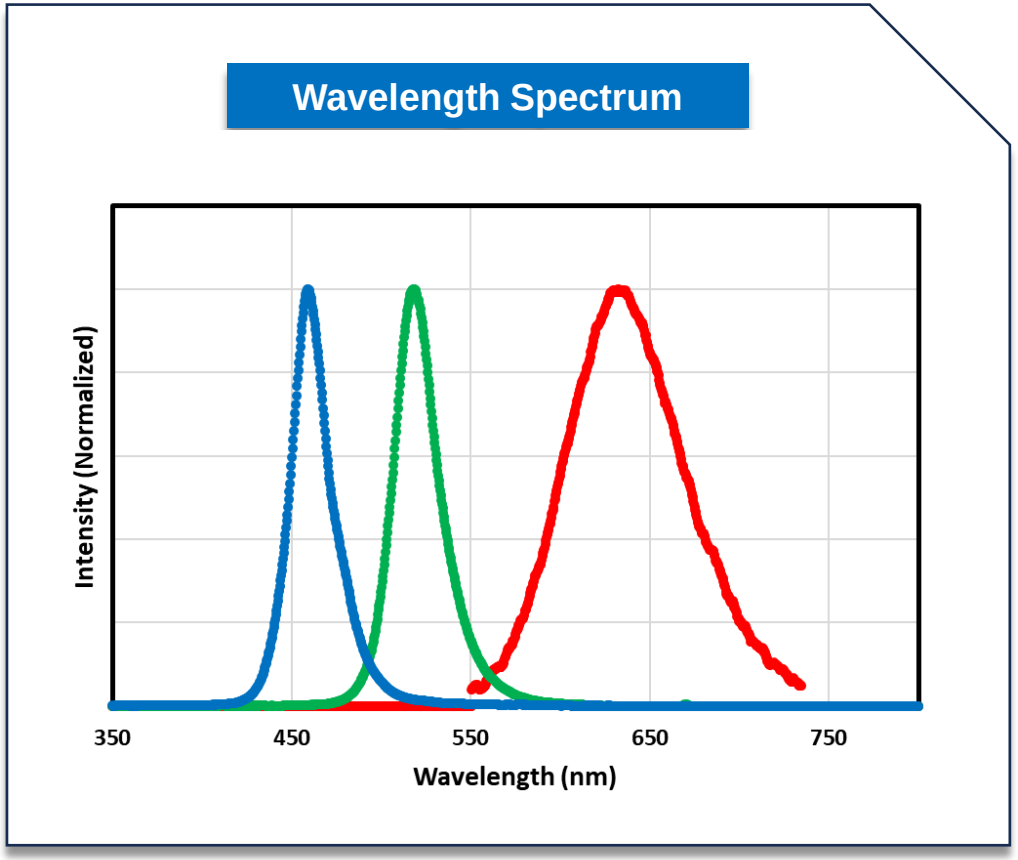


Characteristics of monolithic RGB LED

Electrical & Optical Characteristics of monolithic RGB LED

- *The voltage of blue and green LED chips is higher compared to red LED.*
- *Tunnel junction layer and p-GaN activation for blue and green LEDs need to be optimized.*
- *The FWHM of the wavelength is wider, as the wavelength increases.*



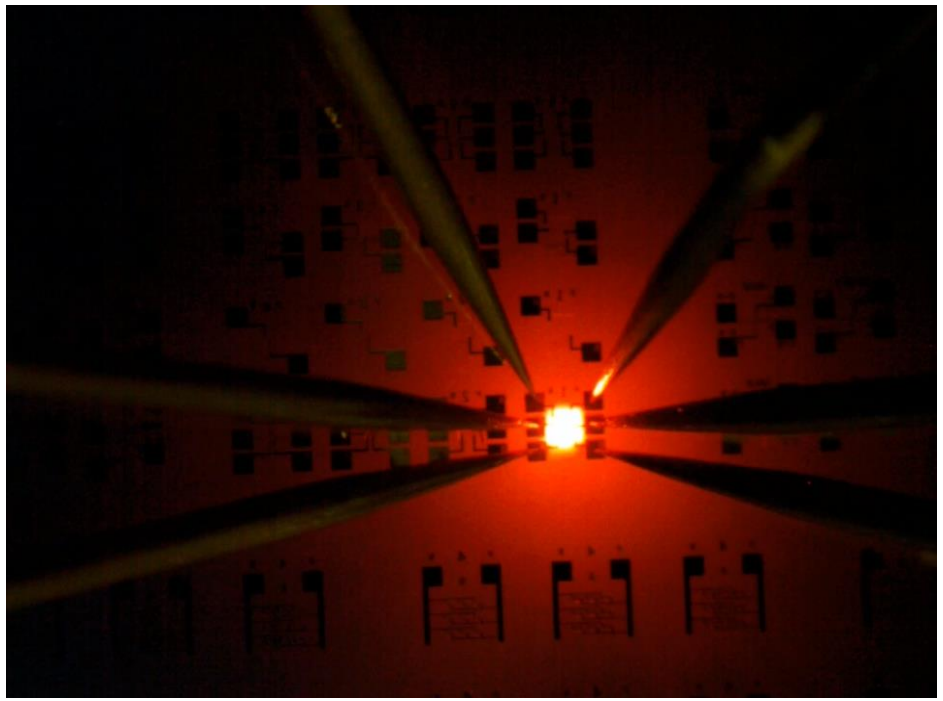


Monolithic RGB LED Chip (6-pad design)

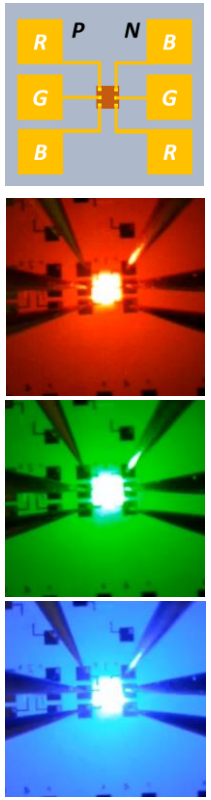
- **RGB colors come from a single wafer.**

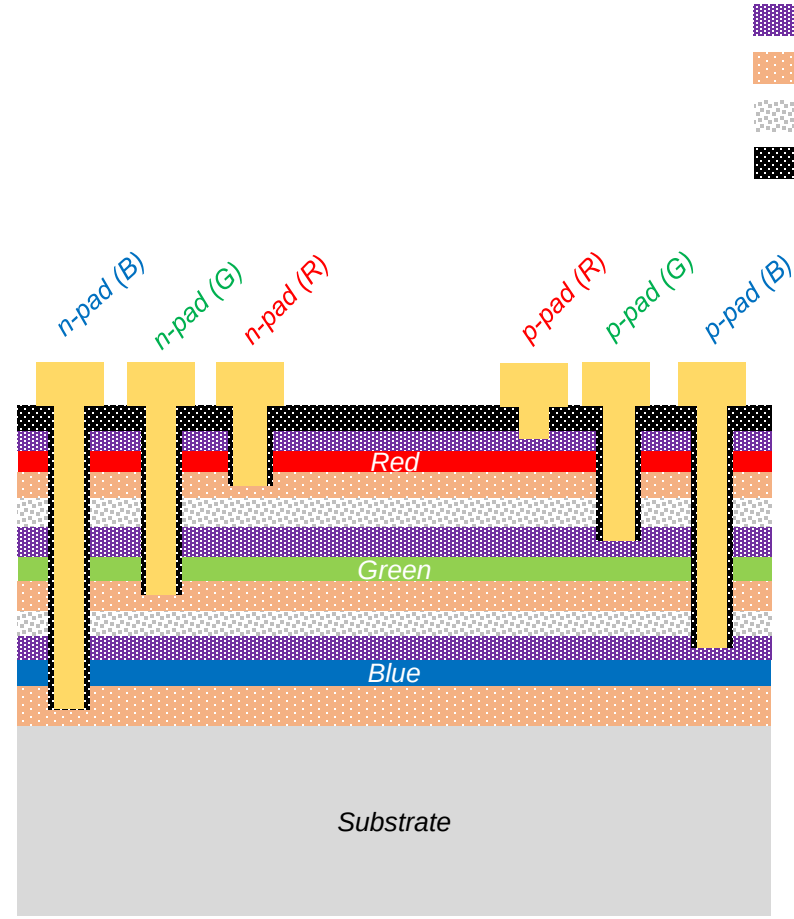
R/G/B Epi-Growth on single wafer

Vertical Type of RGB



100x100um chip, measured with a chip tester



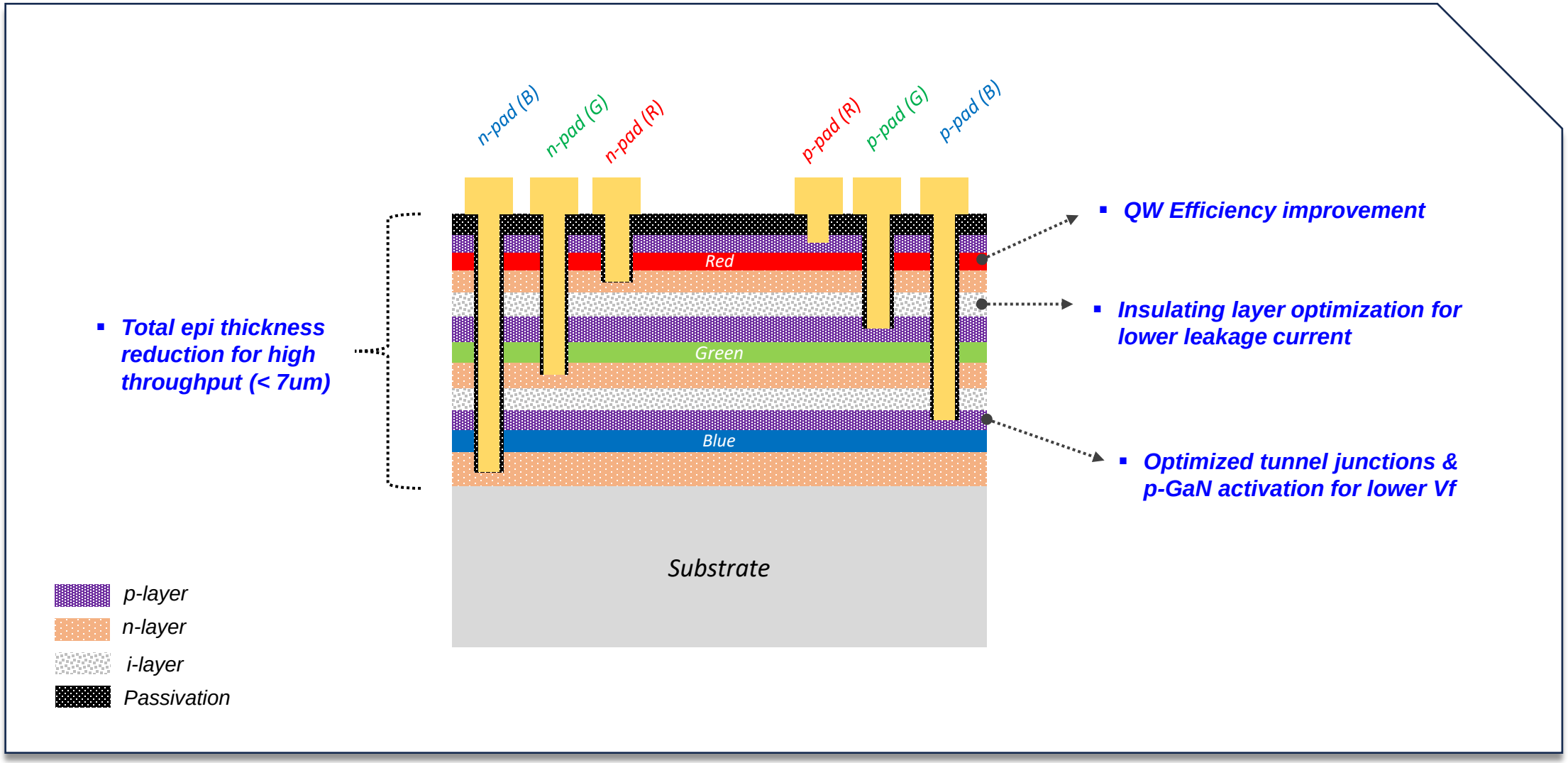


Schematic diagram of vertical type RGB monolithic LED with 6-pads

4. Future Plans

Future Plans

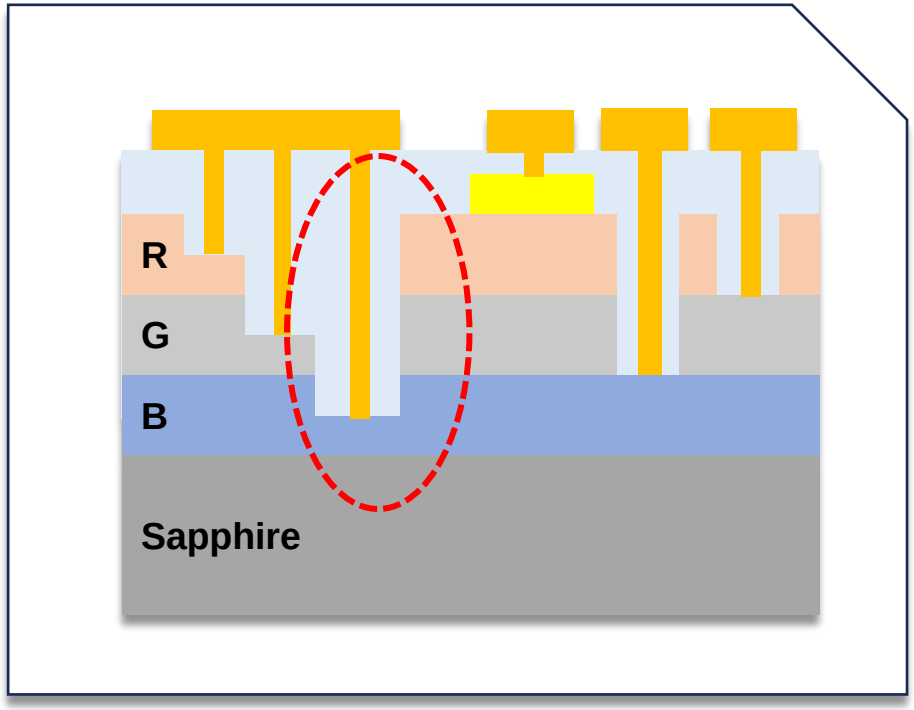
Improvement of Epi layers



- ***Total epi thickness reduction for high throughput (< 7um)***
- ***QW Efficiency improvement***
- ***Insulating layer optimization for lower leakage current***
- ***Optimized tunnel junctions & p-GaN activation for lower Vf***

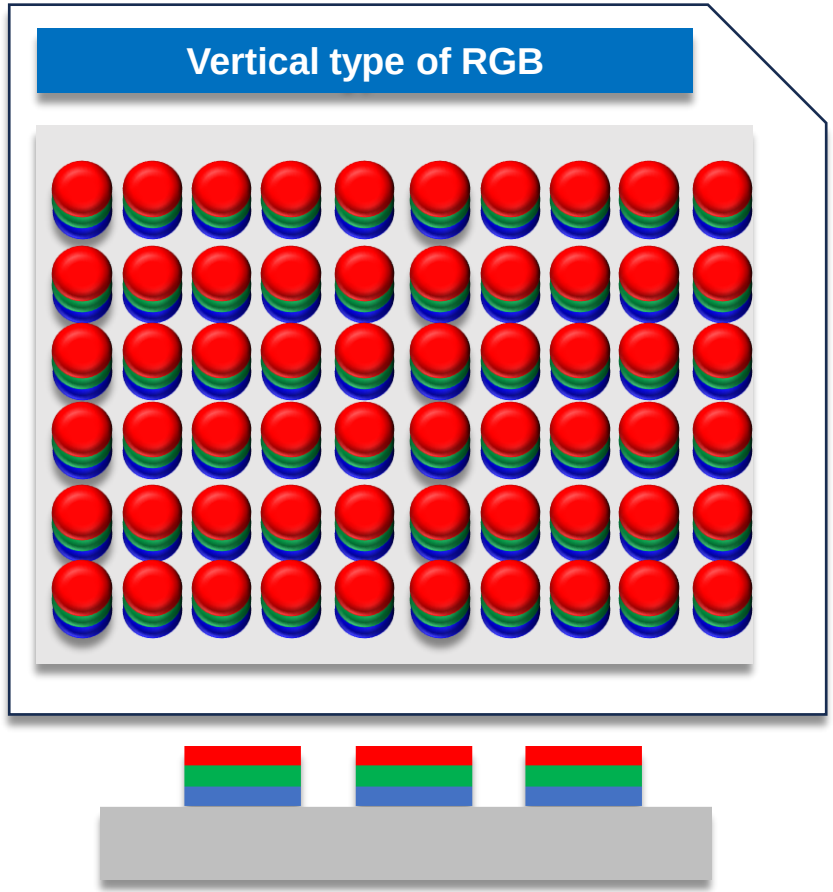
Future Plans

Chip process improvement



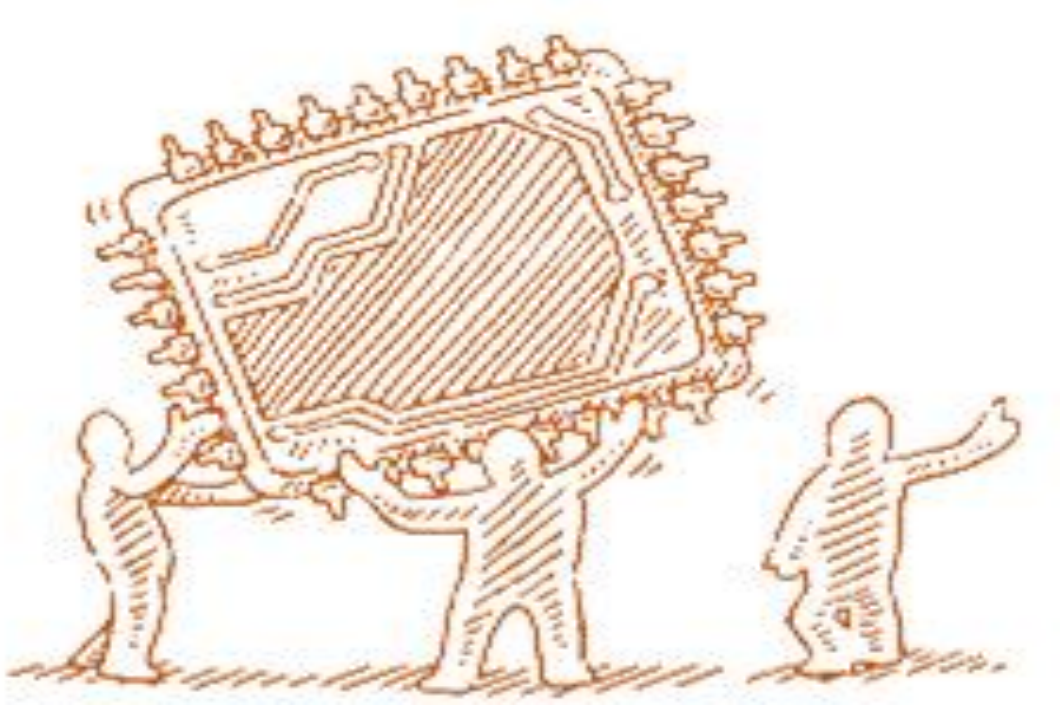
- *Optimized ohmic metal structure for operating stability*
- *Developed Via hole, CMP process*
- *Optimized masking material*

Monolithic RGB display module



※ *Realized full color panel using vertically grown RGB epi*

Thank You



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Soft-EPi