What is the right LED epiwafer strategy for mass production of micro LED displays?

Burkhard Slischka, CEO and co-founder ALLOS Semiconductors
International Micro LED Display Conference 2019, Taipei, 29th August 2019

ALLOS Semiconductors

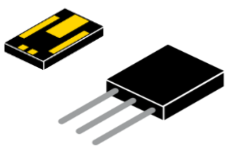
Touch TAIWAN Beyond Display

Photo by Seth Doyle on Unsplash

No need to take photos – write me to get your copy
bs@allos-semiconductors.com

1. Introduction to ALLOS Semiconductors
2. How to make micro LED displays a mass market reality?
3. Manufacturing readiness of ALLOS' epiwafer technology
4. How to work with ALLOS

ALLOS develops and offers GaN-on-Si technology, which is the key enabler for three fast-growing markets

High power electronics (HPE)	Radio frequency devices (RF)	Micro LED / LED
		
GaN-on-Si enables more energy-efficient, less complex and smaller high power electronic (HPE) devices from existing silicon lines	GaN-on-Si provides higher performance, smaller, more energy efficient and lower cost RF devices, for 5G base-stations, smart-phones, CATV, IoT and other RF applications	Only GaN-on-Si allows super-uniform, large diameter, CMOS-compatible 1 bin® epiwafers needed for large-scale micro LED display production

ALLOS* is a leader in GaN-on-Si with 15 years track-record

University of Magdeburg one of three birthplaces of GaN-on-Si world-wide

First to show a 150 mm epiwafer

OSRAM

OSRAM gets license for LED production

AZZURRO closes down

ALLOS Semiconductors

ALLOS buys IP and technology for new business model

ALLOS

Carbon-doping free GaN-on-Si

Veeco ALLOS Semiconductors

FOR IMMEDIATE RELEASE

VEECO AND ALLOS TECHNICAL COLLABORATION ACCELERATES THE PACE FOR 200 MM GAN-ON-SILICON MICROLED APPLICATIONS FOR LEADING GLOBAL CUSTOMERS

ALLOS shows on Veeco Propel < 1 nm wavelength uniformity on 200 mm GaN-on-Si LED epiwafer

end of 90s | 2003 | 2005 | 2009 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

AZZURRO Semiconductors

founded in Magdeburg and becomes the first epiwafer vendor world-wide

Products for HPE, RF and LED introduced

First to offer a commercial 200 mm epiwafer

Total investment exceeds EUR 40 m

EPISTAR

EPISTAR licenses ALLOS' technology

CSindustry awards WINNER

For >1400 V breakdown

iemn

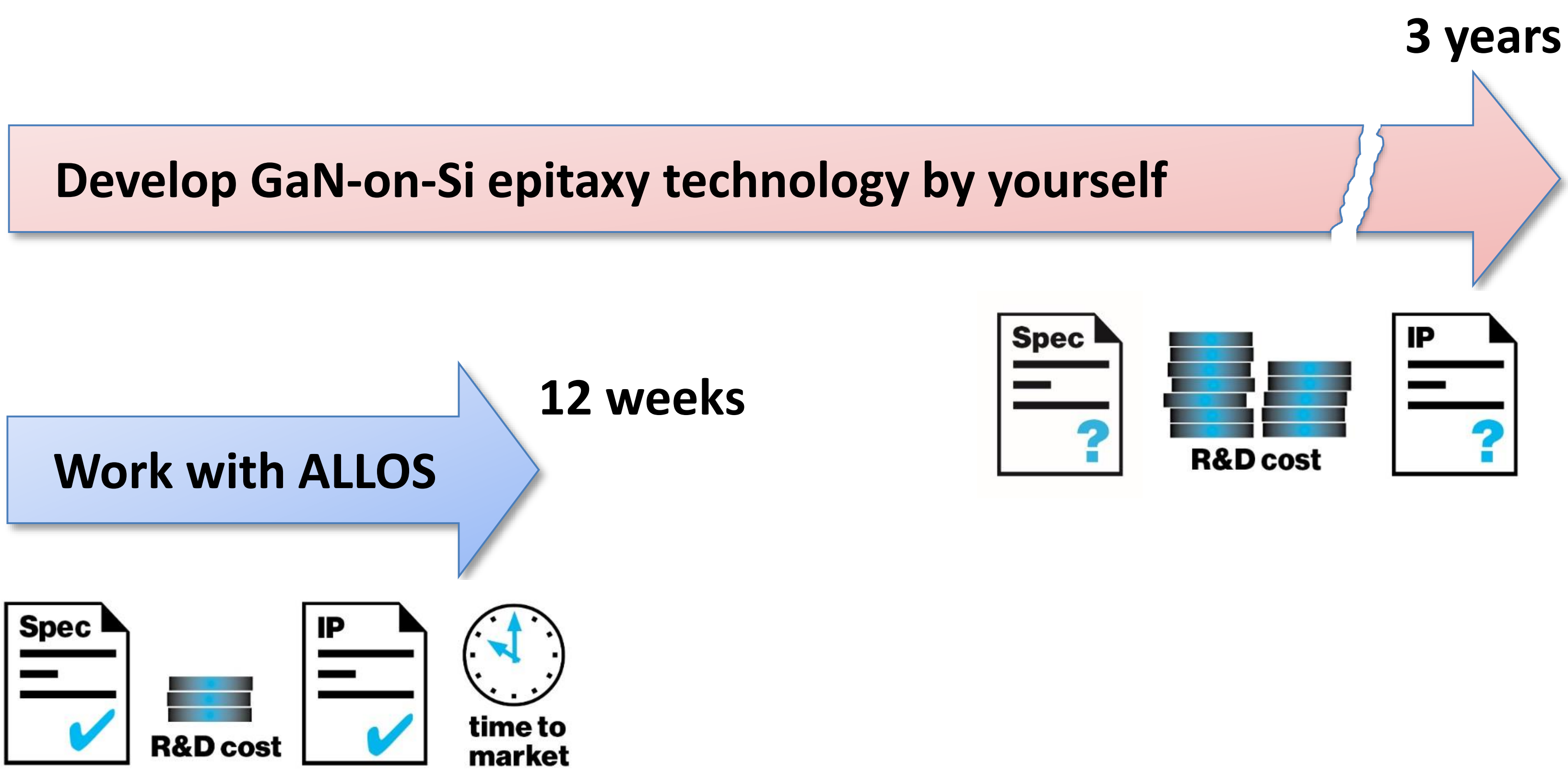
IEMN: "Excellent trapping behavior"

CSindustry awards WINNER

Overcome trade-off between leakage and switching

* ALLOS and its predecessor-company AZZURRO

Technology Transfer is the core of our business offer



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Micro LED displays: Big advantages over LCD and OLED rivals…

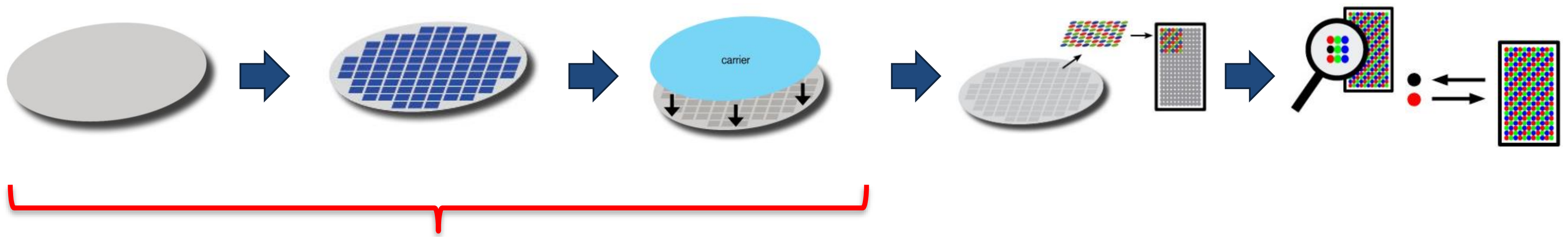
- ✓ Perfect black, brightness and contrast
- ✓ Displays readable even in sunlight
- ✓ High resolution and pixel density
- ✓ More accurate and vivid colors
- ✓ Longer battery runtime
- ✓ Fast refresh rates
- ✓ Wide viewing angles
- ✓ Curved and flexible backplanes
- ✓ Integration of sensors within display
- ✓ Long lifetime, environmental stability
- ✓ Can be integrated into window glass, fabric, building structures or other materials

… but one big challenge prevents mass market break-through

⇨ **Cost**

Where is this cost problem coming from? (1)

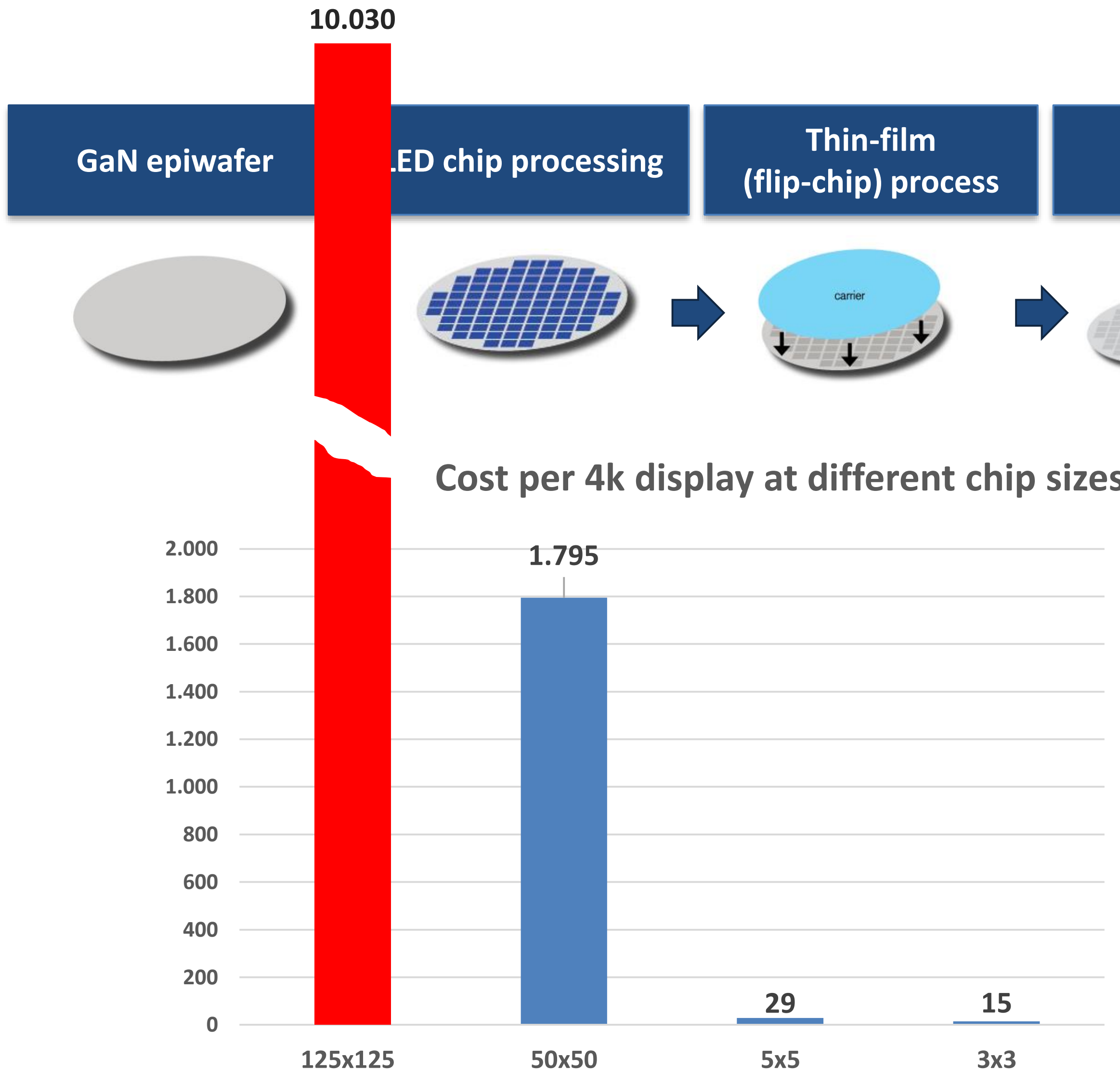
GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



COST ESTIMATE 200 mm	(USD)
Epi cost benchmark LED industry	**232,50**
Processing cost benchmark 200 mm foundry	**90,00**
Thin-film cost benchmark	**30,00**
Sum benchmark cost	**352,50**
100% safety margin for additional tools, initially higher effort, risk, etc.	**352,50**
Realistic cost target for processed wafer*	**705,00**

* Source: ALLOS‘ research; assuming volume production; cost estimate based on blue LED chips on 200 mm wafer ready to be transferred; assuming same area cost for green and red epiwafers

Where is this cost problem coming from? (2)

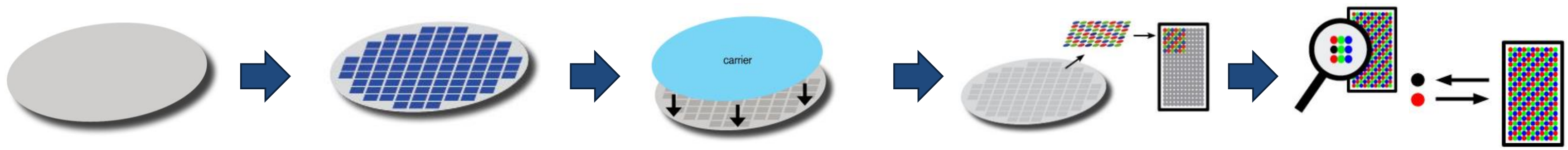


Chip sizes in µm; see previous slide for assumptions

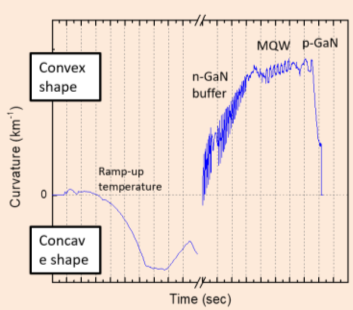
- Even with 100 % safety margin processed micro LED wafers are cost competitive
- Increased usage of smaller chips will drive down cost
- The real challenge is yield
- …and resulting cost in test, transfer and repair

How to make micro LED displays a mass market reality? (1)

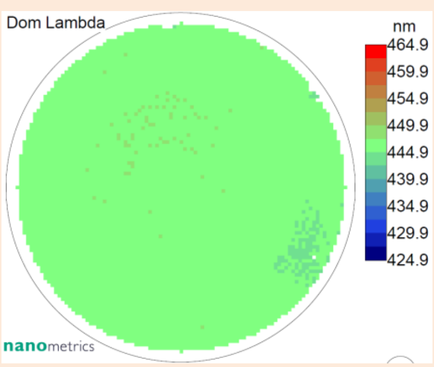
GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



Control growth conditions for LED epiwafer growth



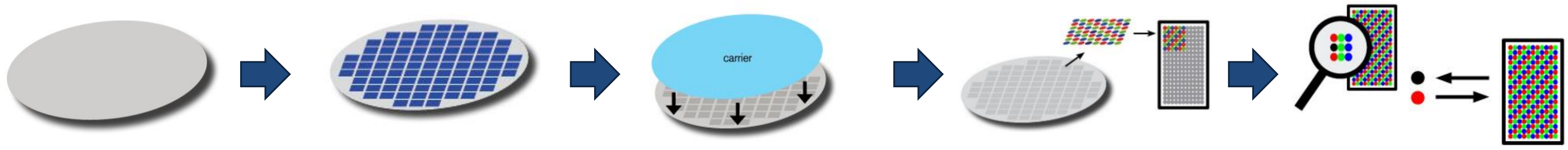
1-bin® wavelength uniformity



Maximize yield and save cost in all later production steps

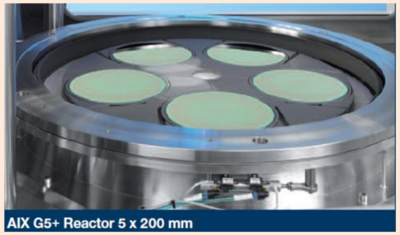
How to make micro LED displays a mass market reality? (2)

GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



Move to larger epiwafer sizes to save cost along the entire value chain

- Better reactor area utilization on most multi-wafer chamber reactors
- Use latest generation single-wafer chamber reactors for 1-bin® wavelength uniformity
- Biggest cost effects are realized at LED chip processing and thin-film processing

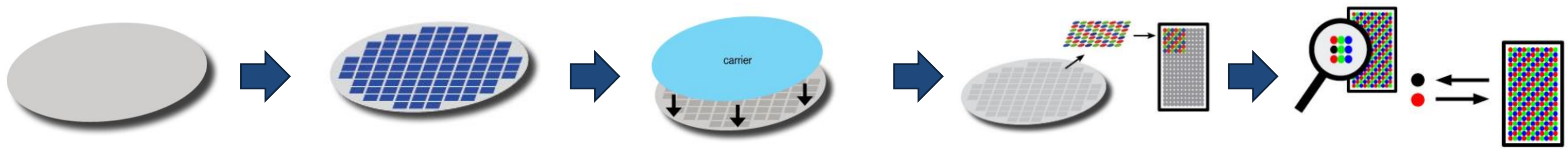


34 % better area utilization for 200 mm vs. 100 mm on G5+

For GaN-on-Si 200 mm is already available, path to 300 mm GaN-on-Si is open

How to make micro LED displays a mass market reality? (3)

GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



High processing requirements for micro LEDs

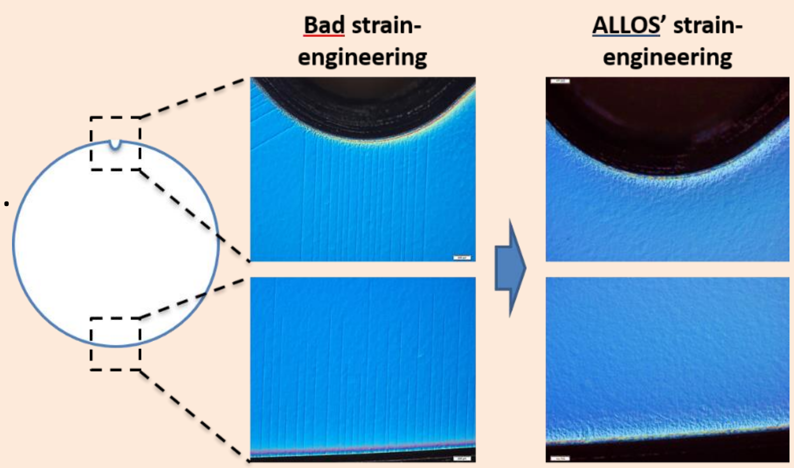
- Precision, processing resolution, particles, etc.

Consider new sourcing models

- Either huge investments for dedicated new fabs…
- Or partner with e.g. low-cost CMOS foundries

Ensure that epiwafers meet requirements for low-cost and high yield processing lines

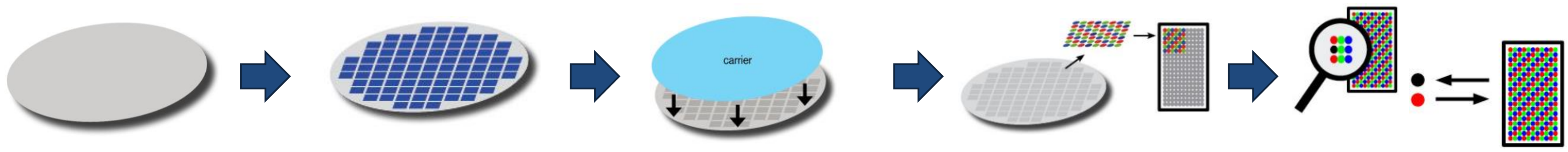
- Wafer cleanliness, thickness, no breakage, etc.
- Minimal wafer bow
- Large wafer diameter (200 or 300 mm)



ALLOS' 200 mm LED epiwafers crack-free even at the edge

How to make micro LED displays a mass market reality? (4)

GaN epiwafer → LED chip processing → Thin-film (flip-chip) process → Mass transfer → Inspection and repair

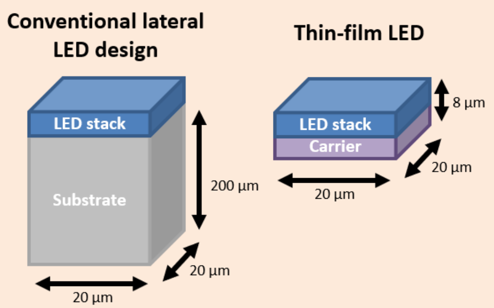


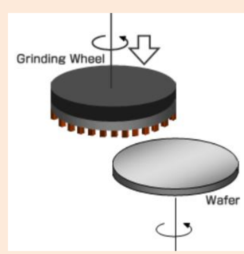
Micro LED require thin-film processes

Easy thinning of GaN-on-Si with standard tools

Bonding requires super-flat wafers

Wafer size match for monolithically integrated designs





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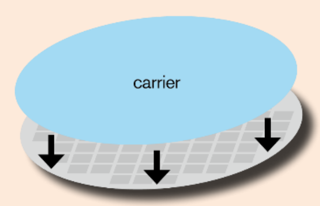
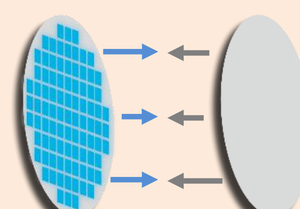


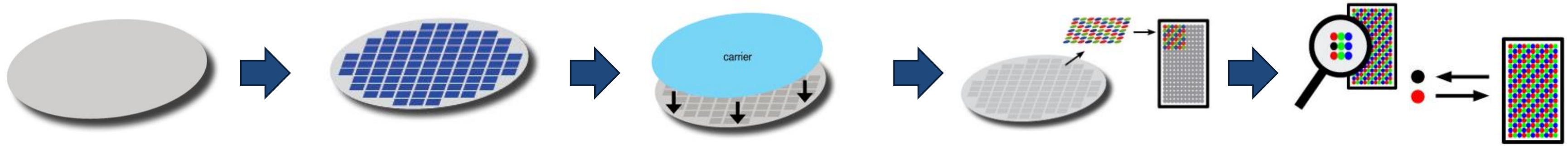


200 mm LED wafer

200 mm backplane

How to make micro LED displays a mass market reality? (5)

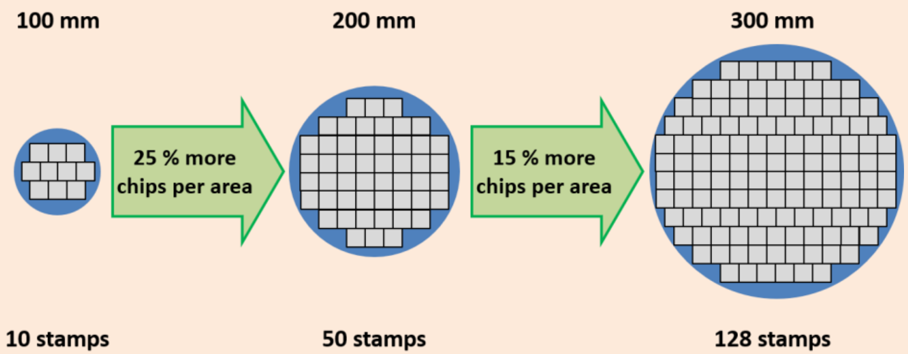
GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



Multiple mass transfer methods have been already demonstrated

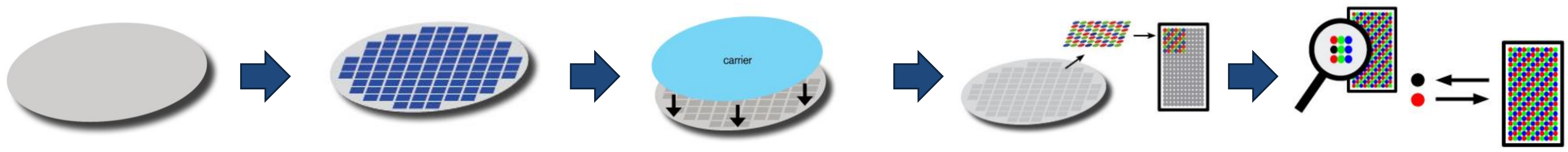
- Pick and place takes too long
- Binning is not an option
- All methods work with GaN-on-Si LED epiwafers

Transfer stamp based methods all benefit from larger epiwafers



How to make micro LED displays a mass market reality? (6)

GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair



Perfect displays required

- Consumers do not accept even one bad pixel
- Even at Six Sigma level 2,488 chips have to be repaired on a 4K display

Relevant yield*	... equals amount of chips failing
90.00000 %	2,488,320.00
95.00000 %	1,244,160.00
99.00000 %	248,832.00
99.90000 %	24,883.2
99.99000 %	2,488.32
99.99900 %	248.83
99.99990 %	24.88
99.99999 %	2.49

- But to test and sort each of 25 million sub-pixels before transfer is very expensive

Two major approaches to solve this dilemma

A. “Blind printing”

- No testing, just transfer and “test” on display
- Repair on display (e.g. using redundancies)

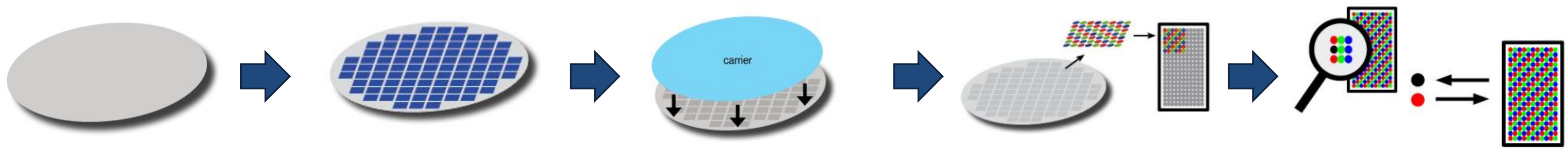
B. “Maximize % of KGD”

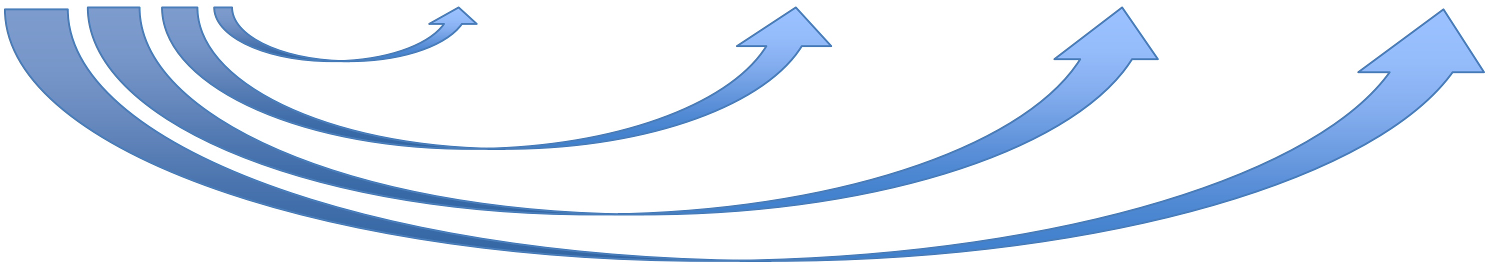
- In-line testing
- Transfer only known good dies / segments
- No or minimal repair needed

Both become cost-efficient only with super uniform epiwafer material

1-bin® epiwafer properties can maximize yield and save cost in all later production steps

GaN epiwafer	LED chip processing	Thin-film (flip-chip) process	Mass transfer	Inspection and repair





Epiwafer uniformity and quality is crucial for yield and cost in all later steps

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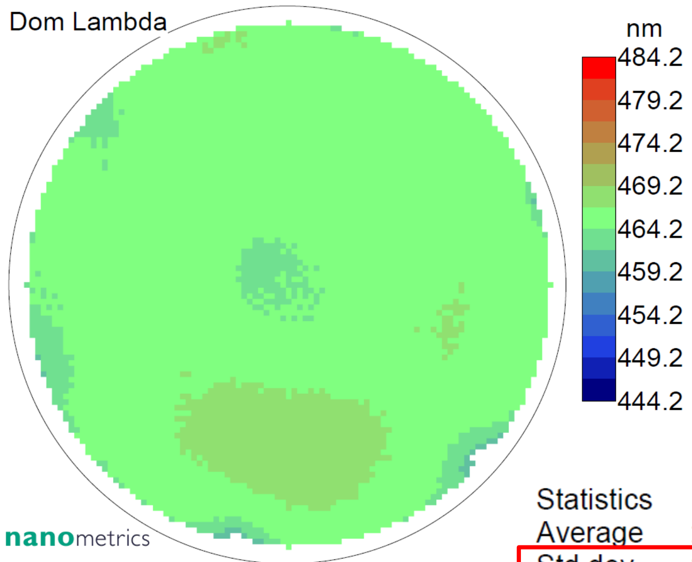
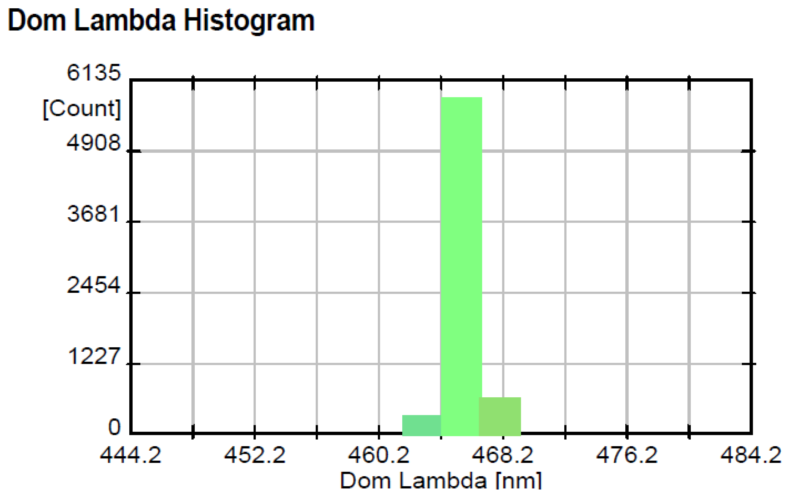
Record-breaking emission uniformity < 1 nm is achieved on 200 mm GaN-on-Si micro LED epiwafer



Statistics

Average	:	465.7 nm
Std dev	:	0.854 nm (0.183 %)
Median	:	465.8 nm
Min	:	462.9 nm
Max	:	467.9 nm

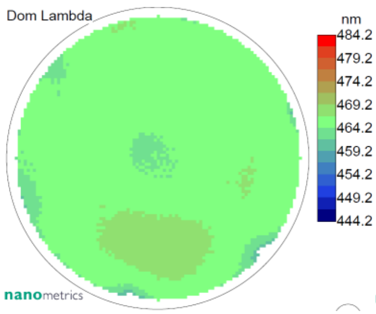


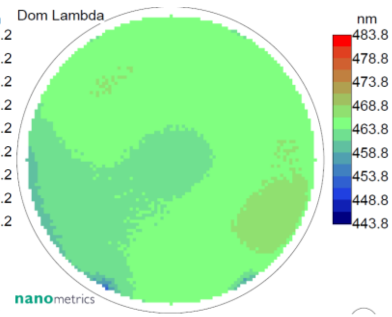
85.3 % in 2.5 nm bin
Min-max = +/- 2.5 nm

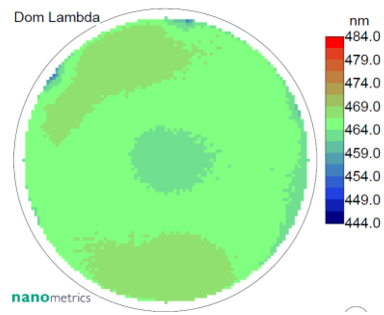
Result from customer project on Veeco Propel in summer 2018

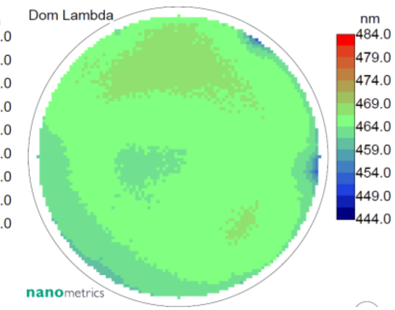
The technology has excellent reproducibility (PL mapping)

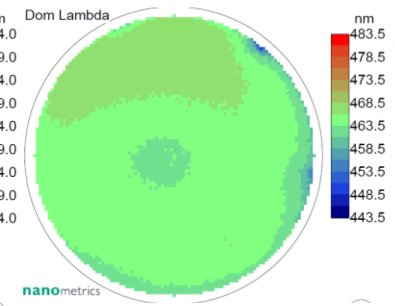
LED run#1	LED run#2	LED run#3	LED run#4	LED run#5







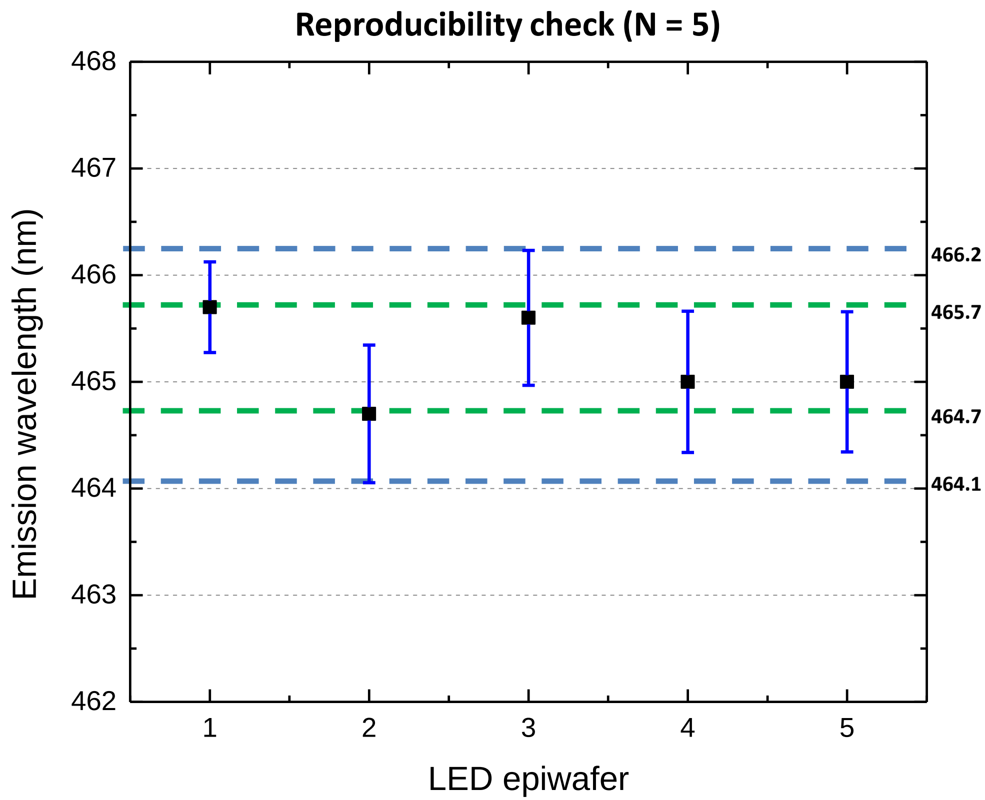




Statistics	LED run#1	LED run#2	LED run#3	LED run#4	LED run#5
Average	465.7 nm	464.7 nm	465.6 nm	465.0 nm	465.0 nm
Std dev	0.854 nm (0.183 %)	1.290 nm (0.278 %)	1.262 nm (0.271 %)	1.323 nm (0.284 %)	1.314 nm (0.283 %)
Median	465.8 nm	465.0 nm	465.6 nm	465.2 nm	465.0 nm
Min	462.9 nm	460.6 nm	461.7 nm	460.6 nm	460.5 nm
Max	467.9 nm	467.2 nm	468.4 nm	467.4 nm	467.8 nm
10% cutoff	464.5 nm	462.9 nm	464.0 nm	463.3 nm	463.3 nm
25% cutoff	465.1 nm	463.8 nm	464.6 nm	464.2 nm	464.2 nm
75% cutoff	466.2 nm	465.6 nm	466.5 nm	466.1 nm	465.8 nm
90% cutoff	466.7 nm	466.2 nm	467.3 nm	466.6 nm	466.9 nm

Result from customer project using the same recipe on Veeco Propel in summer 2018

Peak emission wavelength is controlled within +/- 0.5 nm



STDEV for all within +/- 1.05 nm

Peak wavelength within +/- 0.5 nm

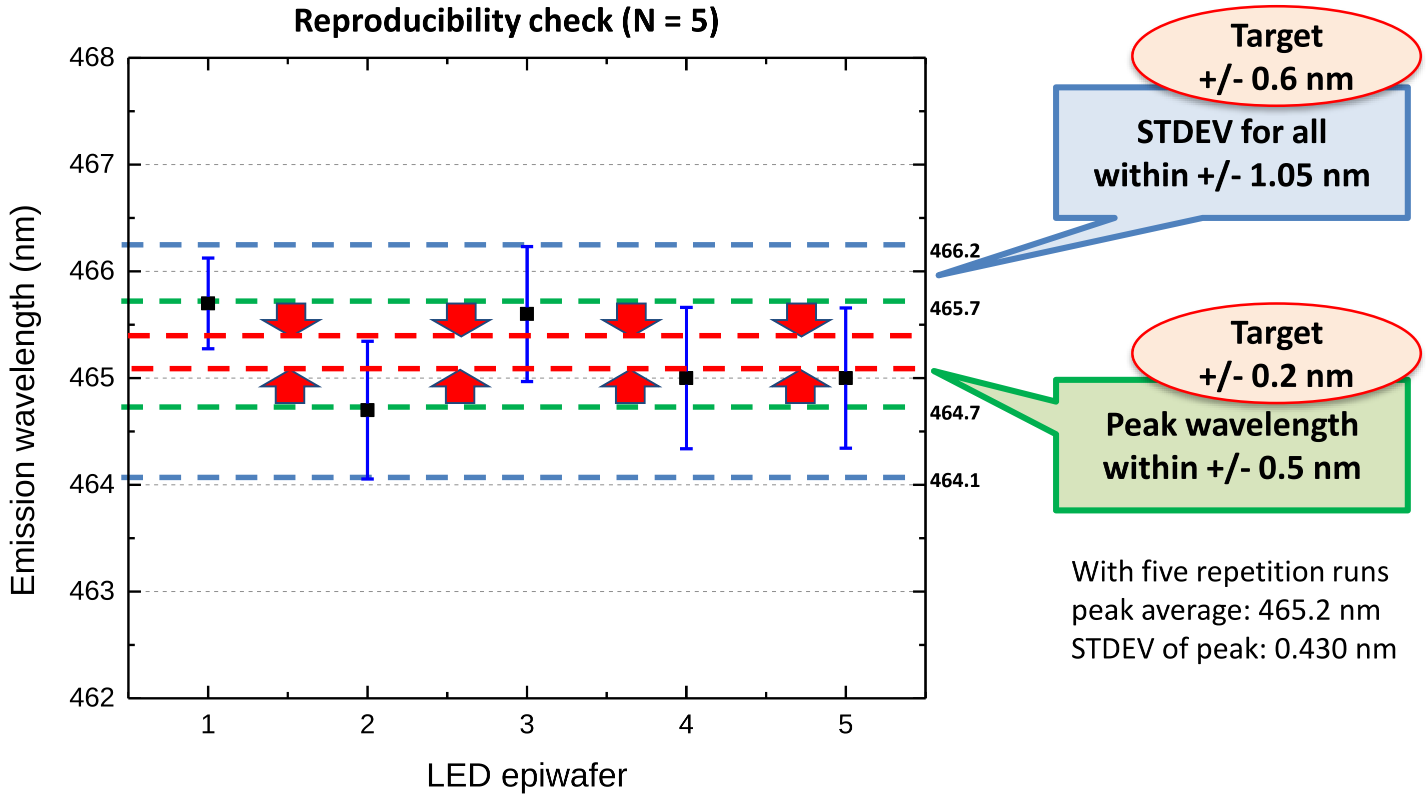
With five repetition runs
peak average: 465.2 nm
STDEV of peak: 0.430 nm

■ Dominant peak emission wavelength

STDEV

Result from customer project using the same recipe on Veeco Propel in summer 2018

...with a development target of +/- 0.2 nm



■ Dominant peak emission wavelength

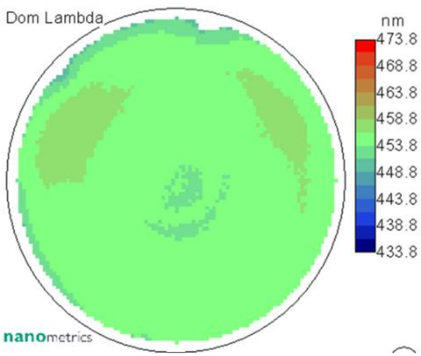
STDEV

With five repetition runs
peak average: 465.2 nm
STDEV of peak: 0.430 nm

Result from customer project using the same recipe on Veeco Propel in summer 2018

Outlook: Continued work shows more world record improvements for wavelength uniformity approaching the goal of +/- 1 nm

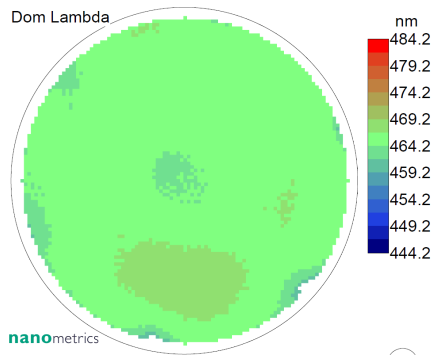
2017



Average: 455.1 nm
STDEV : 0.956 nm
(0.210 %)
Median : 455.1 nm
Min : 452.0 nm
Max : 457.6 nm

1 bin (2.5 nm) = 82.7%
5 nm bin = 99 %
+/- 2.8 nm (min/max)

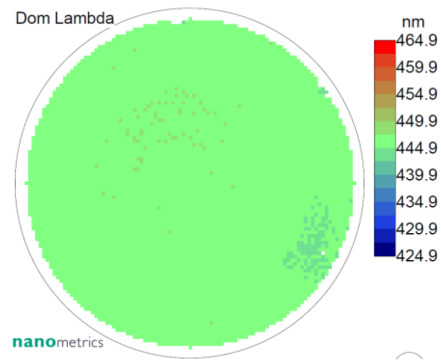
2018



Average: 465.7 nm
STDEV : 0.854 nm
(0.183 %)
Median : 465.8 nm
Min : 462.9 nm
Max : 467.9 nm

1 bin (2.5 nm) = 85.3%
5 nm bin = 100 %
+/- 2.5 nm (min/max)

Feb. 2019



Average: 446.4 nm
STDEV : 0.566 nm
(0.127 %)
Median : 446.4 nm
Min : 444.6 nm
Max : 447.9 nm

1 bin (2.5 nm) = 97.6%
3.3 nm bin = 100 %
+/- 1.65 nm (min/max)

Project stage 2017: Achieving leading uniformity for 200 mm LED epiwafers (irrespective of substrate material)

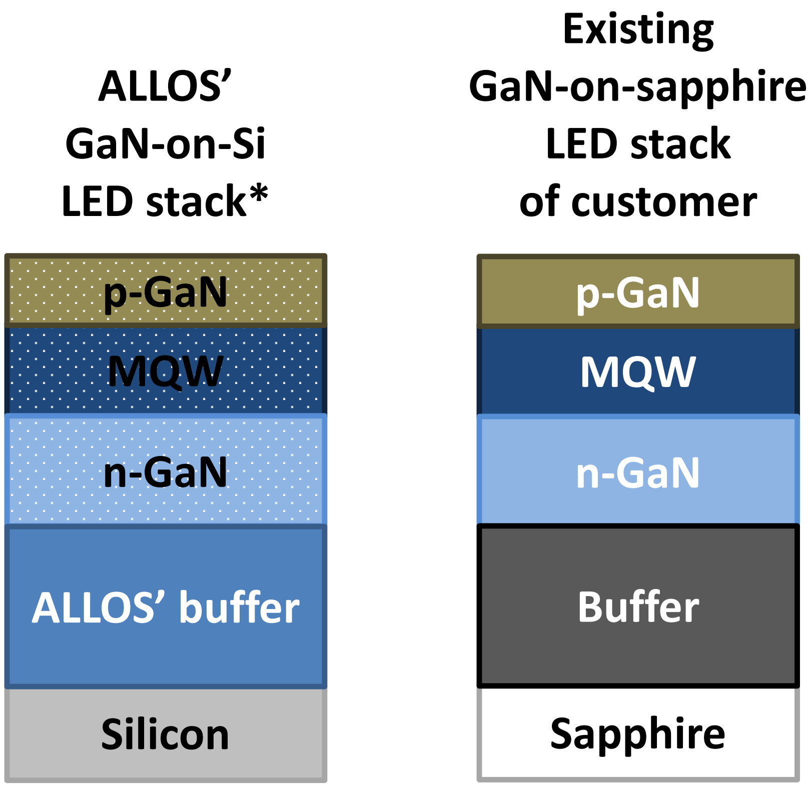
Project stage 2018: Successfully achieving all needed production parameters at the same time with excellent wafer-to-wafer reproducibility

Project stage beginning of 2019: The current project focus is on further advancing the wavelength uniformity towards a true 1 bin® objective (+/- 1 nm); shown are intermediate results

Next will be work on achieving the new leading uniformity results with all production-relevant performance elements while guaranteeing excellent reproducibility ("made for manufacturability").

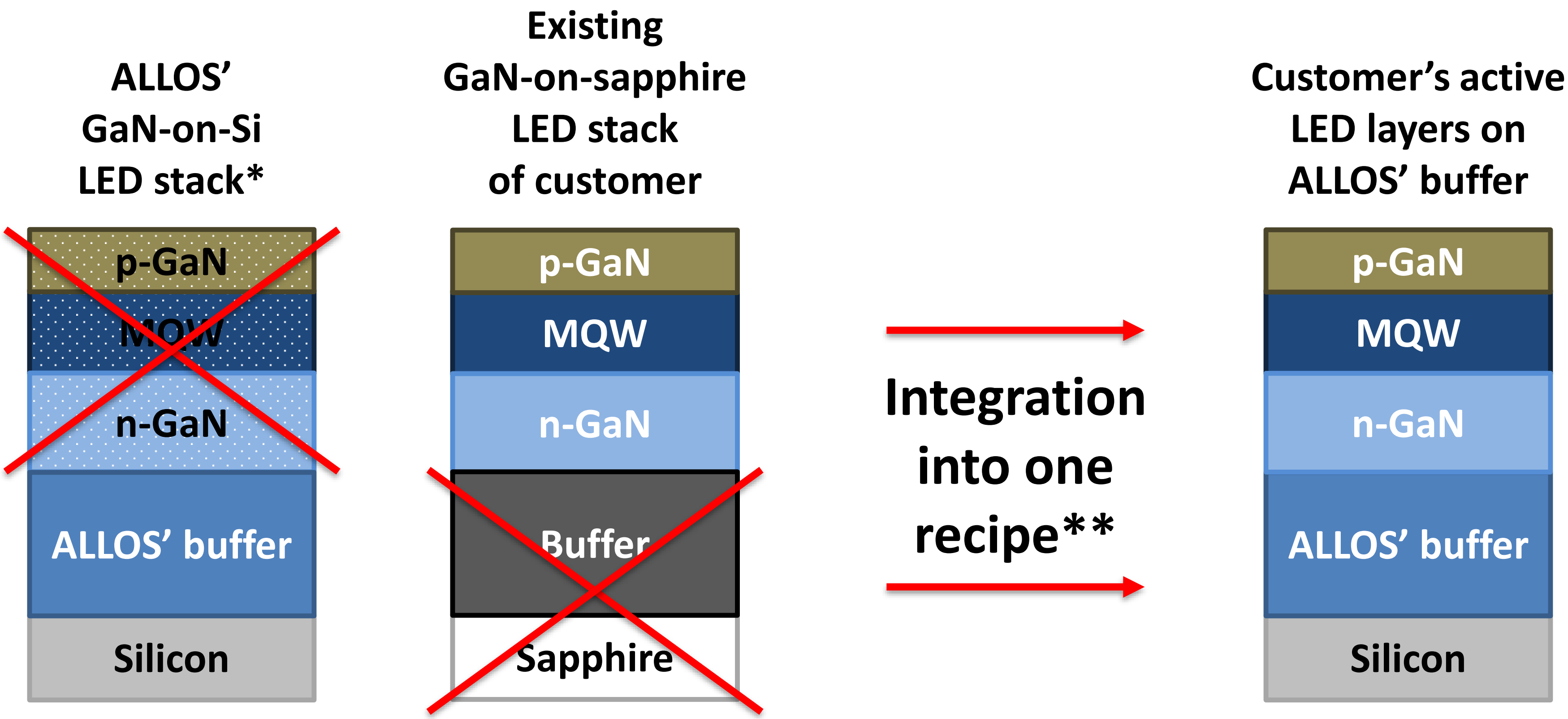
Result from customer project on Veeco Propel

With only a few epi runs any existing active LED layer structure can be integrated on ALLOS' GaN-on-Si buffer



* Transferred to customer in Technology Transfer project

With only a few epi runs any existing active LED layer structure can be integrated on ALLOS' GaN-on-Si buffer



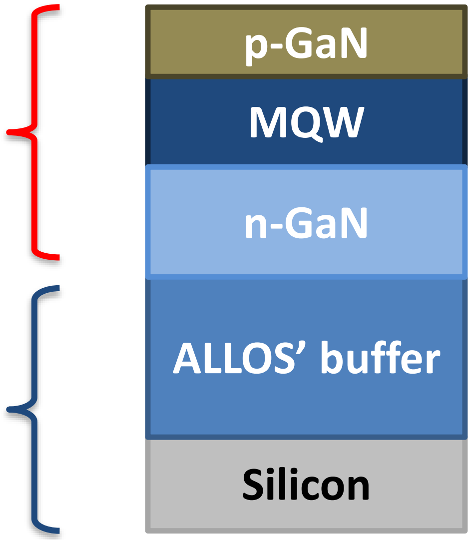
* Transferred to customer in Technology Transfer project
** By either joint team with ALLOS or independently by customer

…allowing the customer to benefit from the best of both technology sets

Customer's active LED layers on ALLOS' buffer

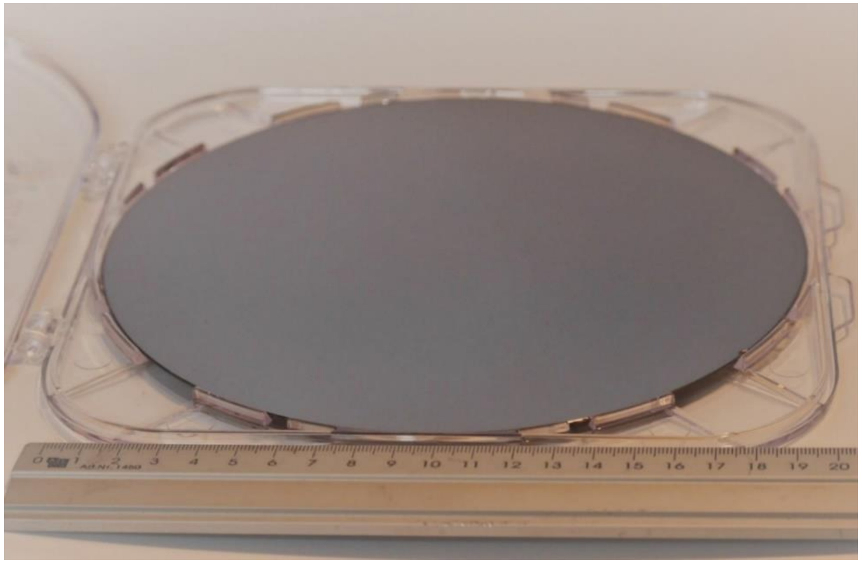
- Same performance (brightness, efficiency) on GaN-on-Si as on GaN-on-sapphire
- Existing IP protection
- Preserve learnings for LED design / epi / processing interaction

- Industry-leading GaN-on-Si performance with >15 years' of technology development background
- Best wavelength uniformity (1-bin®)
- Large diameter, flat and CMOS-ready epiwafer



ALLOS' GaN-on-Si epiwafer fulfils all requirements for micro LED display mass production at the same time

200 mm GaN-on-Si epiwafer of ALLOS for micro LED



1 bin® wavelength uniformity ✓

Existing MQW from on-sapphire can be easily integrated ✓

Best GaN-on-Si crystal quality in the industry

- Same low defect level as on GaN-on-sapphire: TDD ~2 x 10^8 cm^{-2}
- Enables excellent LED performance ✓

Large diameter and CMOS-ready

- 100 to 200 mm, next 300 mm
- 30 µm bow for 725 µm thickness at 200 mm
- No cracks, no residual strain ✓

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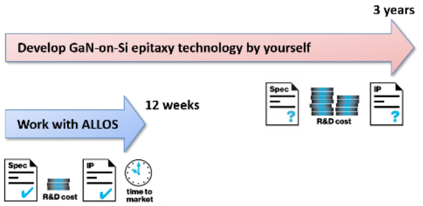
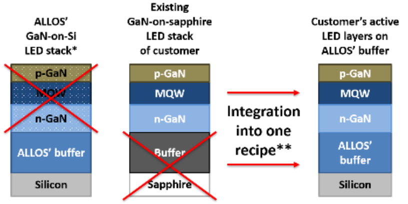
Proposed steps of working with ALLOS

Step 1: Purchase sample package and evaluate ALLOS' LED epiwafers

Step 2: Agree license and transfer ALLOS' technology to your* reactor



Step 3: Integrate your* light emitting epi-structure (optional)



Step 4: Optimize epi-stack for micro LED volume manufacturing (optional)

* Your or your partner's

Summary

- To become ready for volume production of micro LEDs the problem of insufficient yield needs to be solved
- Emission wavelength uniformity is the biggest single driver to achieve that objective
- The right (large diameter, high crystal quality, CMOS-ready) GaN-on-Si epiwafer technology can further enable cost savings in all following production steps
- ALLOS offers its GaN-on-Si technology for licensing and technology transfer and is open to work with you in your long-term projects

CSindustry awards

W I N N E R

2018 and 2019

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