MicroLED Display Integration on 300mm Advanced CMOS Platform

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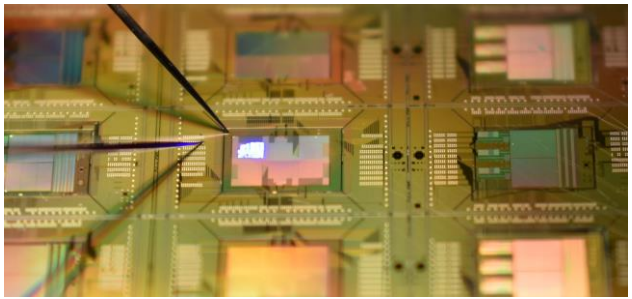
COMPANY OVERVIEW

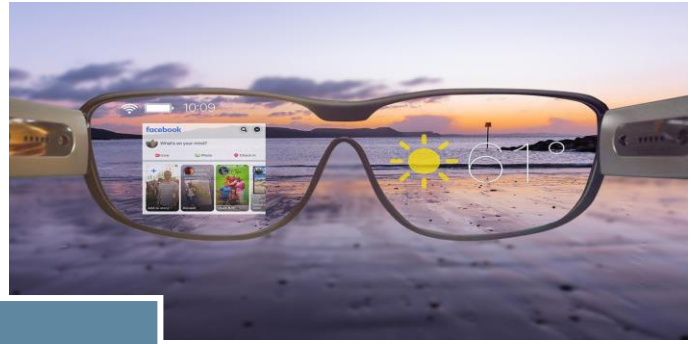
Company:	Micledi Microdisplays
Vertical:	Consumer Electronics, AR
Product:	MicroLED Displays
Business model:	B2B Fabless Hardware Component Sales
Technology IP:	Spin-out of IMEC in 2019
USP:	Size, Power Efficiency, Image Quality
Financials:	Pre-Revenue
Investment:	>10MEUR



MARKET DEVELOPMENT

Today: Large, Heavy, Expensive, Poor Image

Tomorrow: Compact, Attractive, Low-cost, Low Power, Beautiful Image



The dream

The big elephant in the room. How to solve:

- Accommodation and Convergence
- Occlusion

TECHNICAL PROBLEM STATEMENT

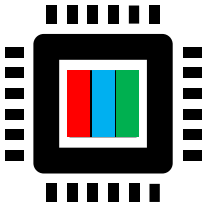
Resolution

<3um sub-pixel pitch

Brightness

> 1Mnit @ D65 white point

AR display



Power consumption

<1W @ usage scenario

Image quality

- 16bit/color
- De Mura / Gamma
- Lifetime degradation

Cost-effective volume manufacturing

< 100$ per module

STATE-OF-THE-ART

AR/CMOS µLED display (excl. µLED flat panel displays)

Companies with own known development efforts:

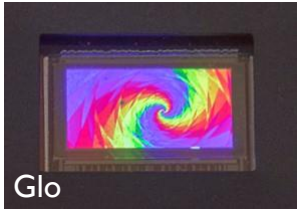
	Start-up1	Company1	Start-up2	Company2	Start-up3	Start-up4	R&D1	Start-up5
CMOS integration	D2W	D2W	Subsequent 3D	W2W	polysilicon TFT	D2W / W2W	subsequent 3D	D2W
Color creation	Downconversion	RGB transfer	Combiner	n.a.	Downconversion	Downconversion	n.a.	Stacked QW
Wafer size LED [mm]	100	200	100	200	150	200	200	150
Wafer size CMOS [mm]	200	200	200	200	150	200	200	200
Wafer level optics solution	No	No	Yes	Yes	No	No	No	Yes
Manufactuability / yield / cost								
Issues with image quality								
Issues with brightness								
Issues with resolution								

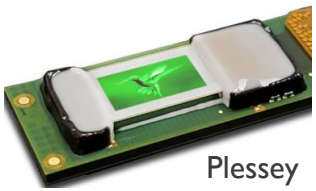
	Company3	Start-up6	Company4	Start-up7	Company5	MICLEDI	Company6
CMOS integration	D2W and W2W	subsequent 3D	D2W	D2W	D2W	W2W	D2W
Color creation	Downconversion / Combiner	n.a.	Downconversion	RGB transfer	RGB NW growth	Combiner	n.a.
Wafer size LED [mm]	150/200	n.a.	150	n.a.	n.a.	300	n.a.
Wafer size CMOS [mm]	200	n.a.	200	n.a.	200	300	n.a.

Large competition
Large investment
Very different technology

- CMOS integration (4x routes)
- RGB LED (8x routes)
- Optics (3-4x routes)
- Driving and compensation (xx routes)

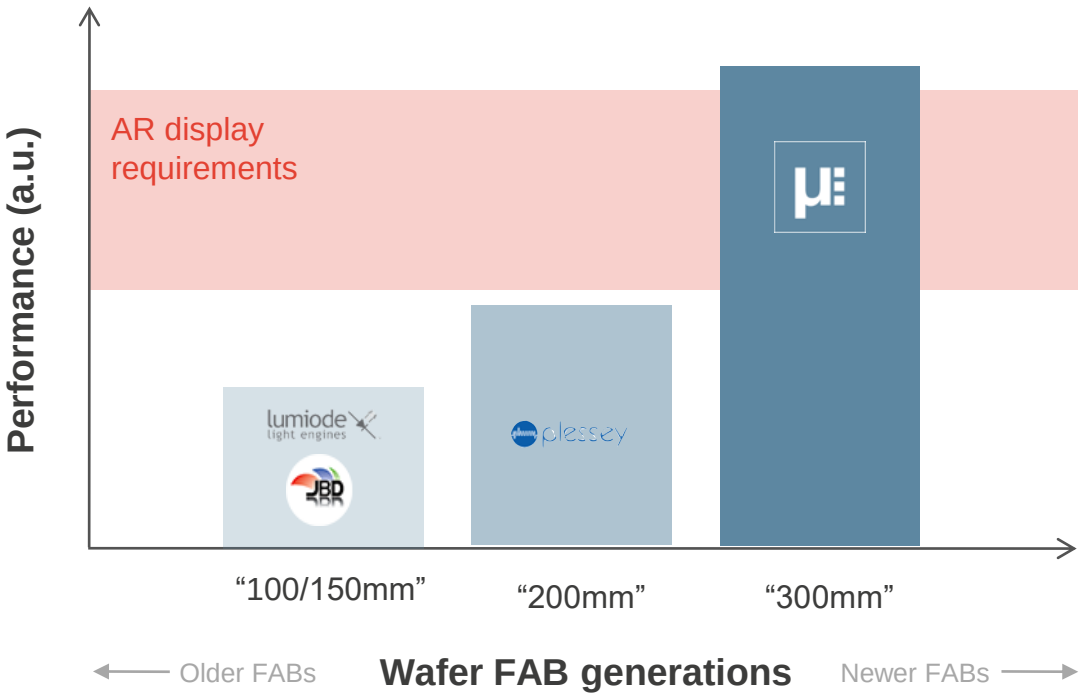
Aledia
Compound Photonics
EpiPix
META
Lumiode
Lumens
MojoVision
NS Nanotech
Plessey
Ostendo
Raxium
Raysolve
JBD
Sharp
VueReal
..many more





UNIQUENESS OF MICLEDI TECHNOLOGY

LEVERAGING MOST ADVANCED EQUIPMENT IN SEMI INDUSTRY



MicroLED with AR specs is **only possible in advanced 300mm** (foundry) manufacturing

- advanced node driving ASIC (<45nm)
- advanced litho for wfr level optics (CD<100nm, overlay<20nm)
- tight W2W hybrid bonding overlay specs (<200nm)

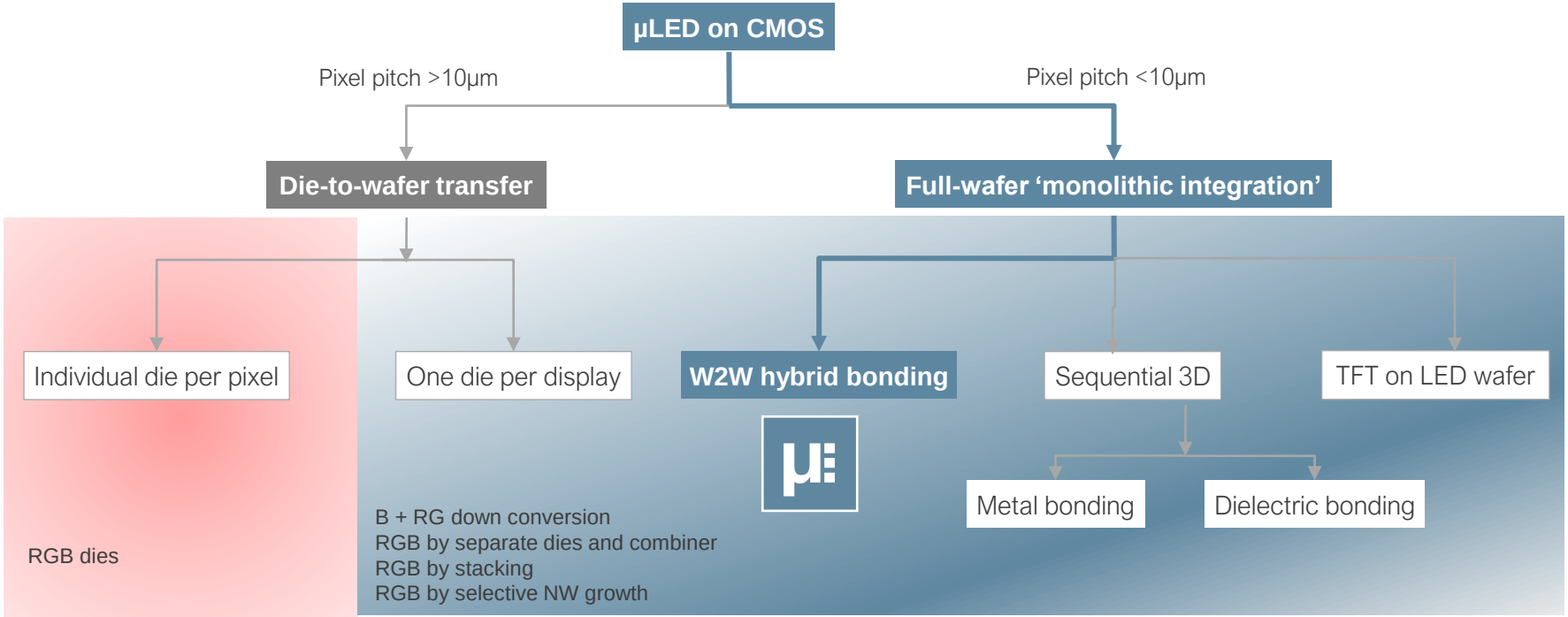
Requires **dedicated technology development**

Uniqueness: Micledi is the only startup for microLED in 300mm

*Full flow development @imec with standard high-throughput automatic production tools

INTEGRATION CHALLENGES

MICRO-LED ON CMOS



RGB COLOR

VS SPECS FOR AR WAVEGUIDE OPTICS

	RGB pixel level die assembly	RBG dies and combiner optics	RG down conversion	Selective RGB templated growth (e.g., NW)
RGB color	pixel-by-pixel row-by-row	die-by-die	pixel-by-pixel	pixel-by-pixel
Pixel density				
Brightness				
Yield				
System cost				
Display size				
Image quality				
Lifetime				

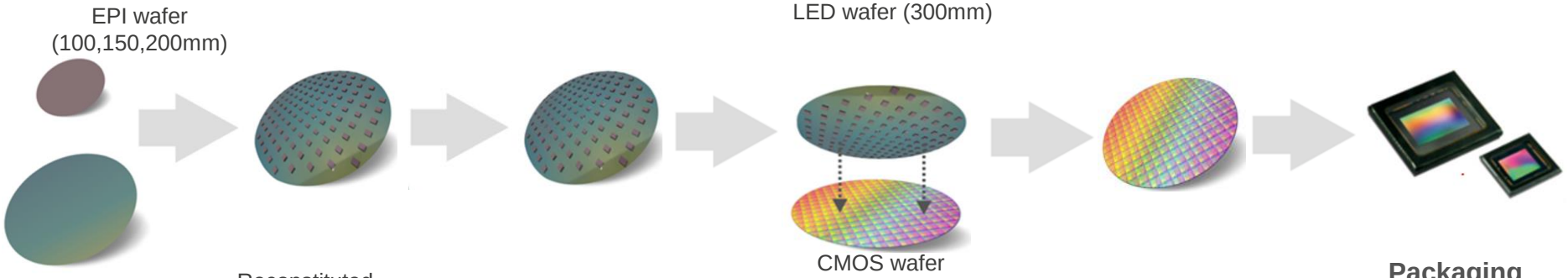
Alternative RGB routes explored by different companies

- Stacked RGB QW (W2W bonding)
- Stacked RGB QW (epi overgrowth/Multi-contact)
- RGB etched nanopillar

1. The display size is limited by the pixel density. Added constraint is CMOS driver size.
2. RGB die-by-die and RGB pixel-by-pixel have the same size constraints.
3. CMOS power consumption scales with number of pixel and image quality.
4. LED power consumption scales with emissive area.

LED PROCESS FLOW FOR W2W BONDING

HIGH LEVEL OVERVIEW



Si wafer
(300mm)

Reconstituted
foundry compatible
EPI wafer (300mm Si-substrate)

LED processing
LED arrays

Hybrid W2W bonding
LED integration with CMOS
- 3µ pitch W2W bonding
- Si back-grinding

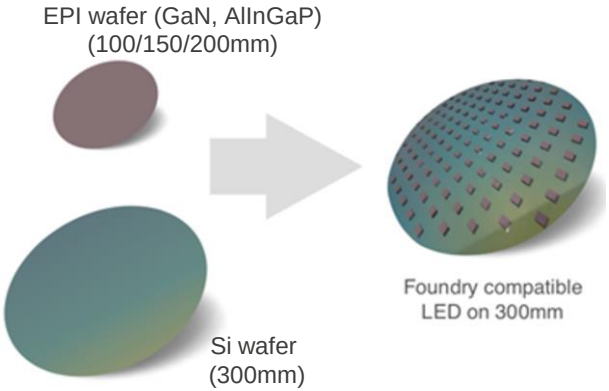
Front side processes
Common anode + lens

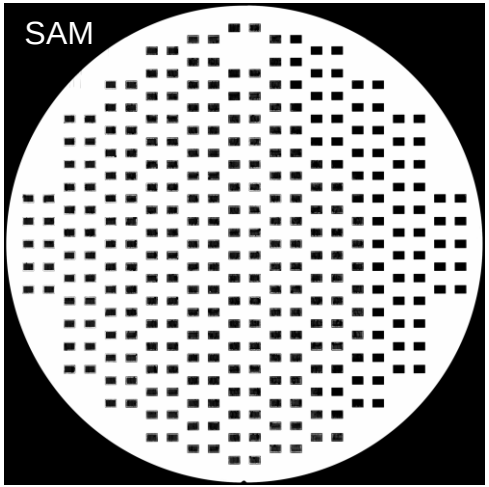
Packaging
- Testing
- Dicing
- Packaging

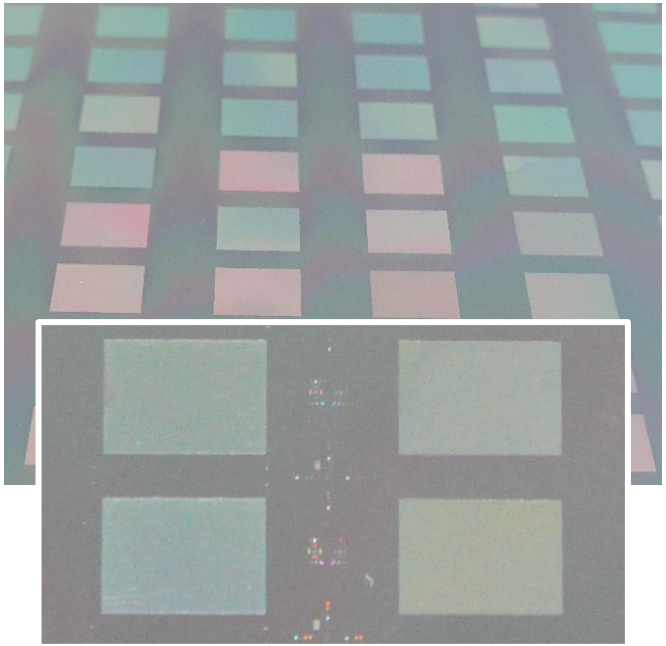
Issues solved by MICLEDI	• Defectivity • No 300mm epi • Residual stress	• CMOS compatible LED process flow	• CMOS/LED tight pitch integration	• LED performance • Beam shaping	• Driving • Calibration

300MM EPI SOLUTION

EPI WAFER RECONSTITUTION



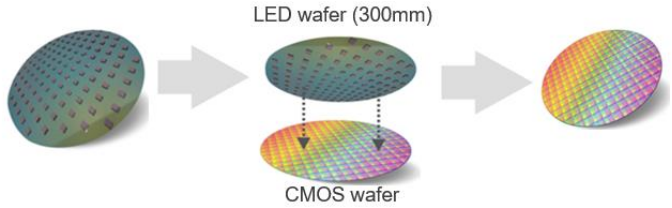


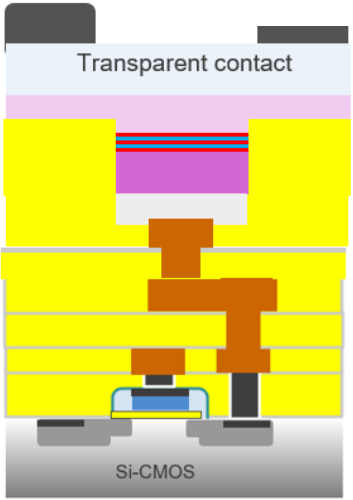


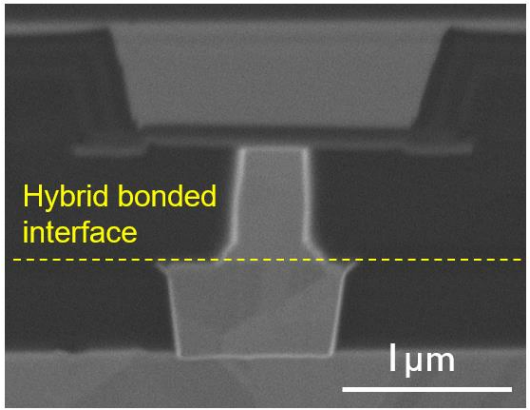
- Planarized 300mm reconstituted epi-wafer on standard Si-wafer
- Die attach yield up to 100%
- Pre-selection of epi dies for low-defectivity & optical properties possible
- Wafer bow < 20µm and no residual stress
- n/QW/p LED epi – layer with buffer removal < 1.5µm thickness
- Planarization verified by W2W bonding

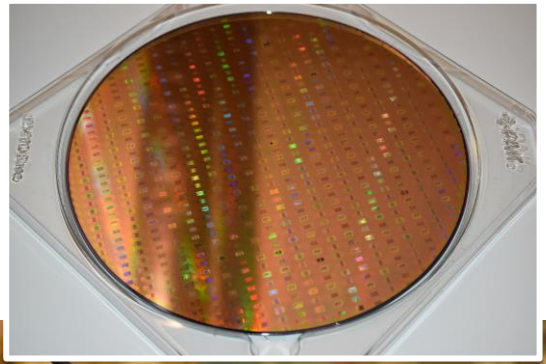
DISPLAY INTEGRATION

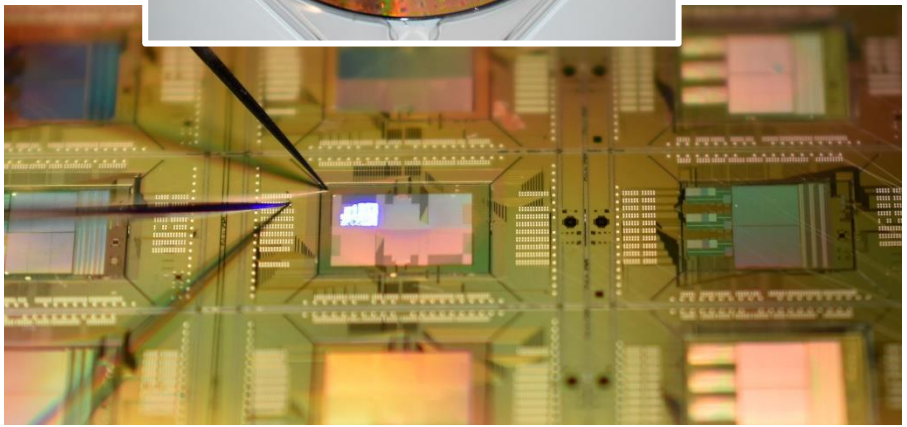
300MM CMOS FAB COMPATIBLE PROCESS FLOW









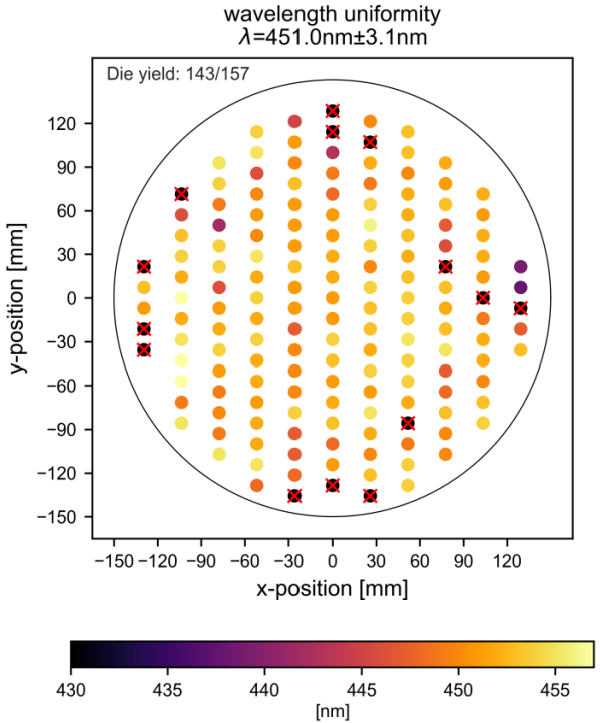


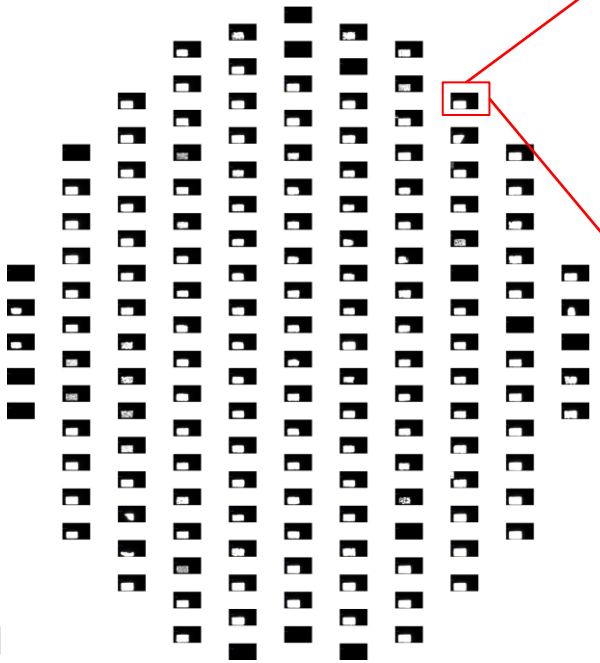
W2W hybrid bonding of CMOS with GaN LED
- Pixel pitch 3µm hexagon = 9150ppi
- overlay variation < 200nm across 300mm wafer
- No active CMOS in pathfinder lot; only passive matrix

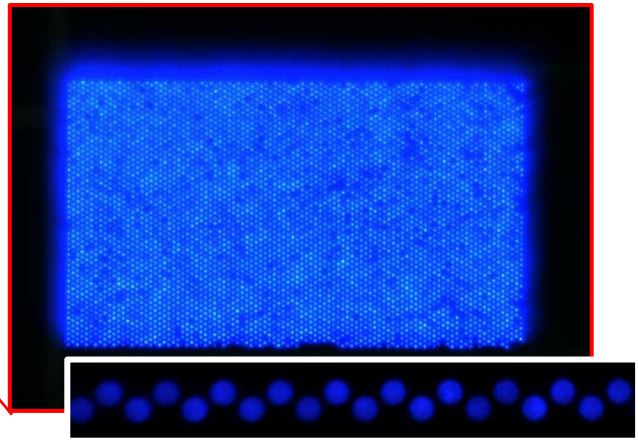
WAFER MAPPING DATA

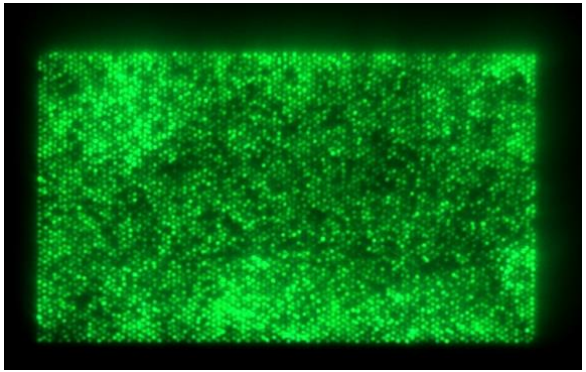
50 x 100 array with 3µm pitch / MESA = 2µm

More then 90% of passive matrix test LED arrays lighten up





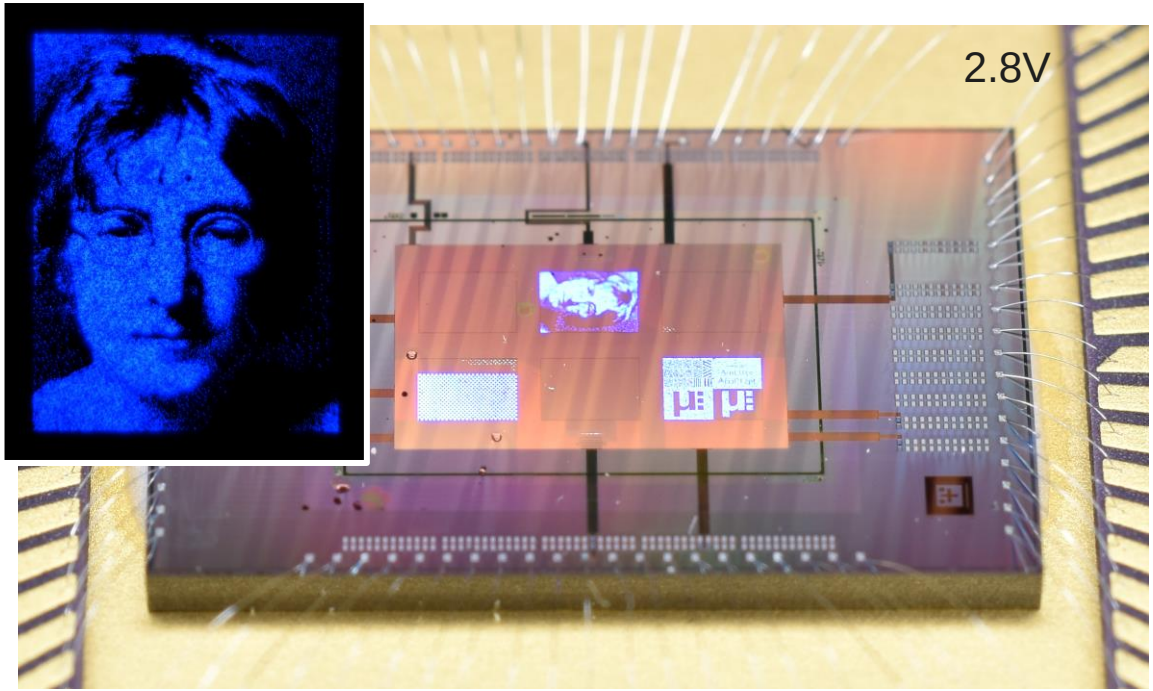


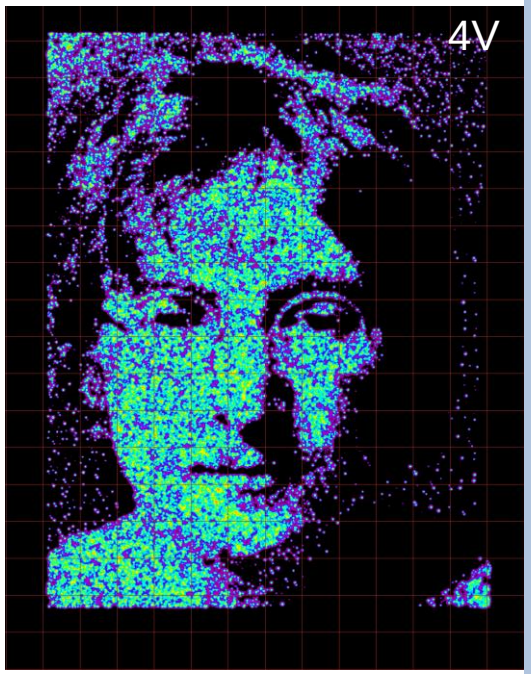


DISPLAY TEST STRUCTURES

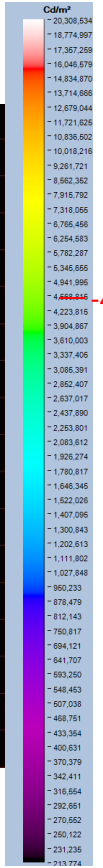
480X320 PASSIVE MATRIX SUB-ARRAYS WITH 3UM PITCH

- >1Mnits@ 4V
- fill facture (up to 63%)





Radiance camera

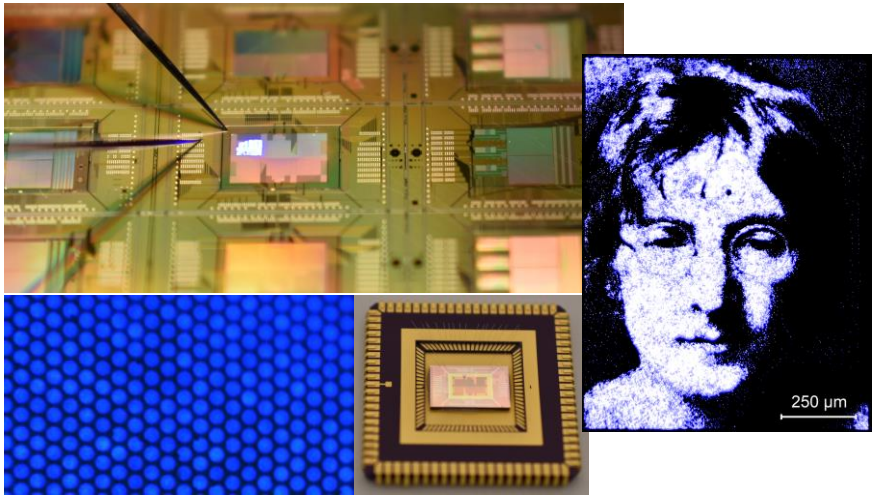


-4Mnits

ALL COLOR

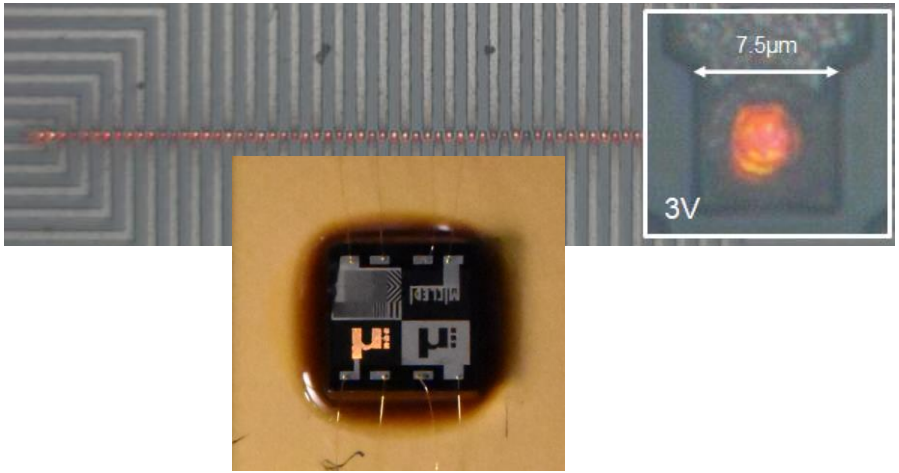
FIRST PRODUCT GENERATION: GAN ON SI FOR RGB

Devices for integration flow development



Design rule	MESA = 0.5-2.5µm, Pitch = 3µm hexagon, window=100%
Process flow	300mm GaN RC with W2W hybrid bonding;
Layout	passive matrix
Common potential	Anode
Outcoupling	Top emission; backside mirror + DBR; aperture =63%;

Devices for material and passivation characterization



Design rule	MESA = 3µm, Pitch = 6µm square, window=1.3µm
Process flow	200mm GaN on Si ;
Layout	passive matrix
Common potential	Cathode
Outcoupling	Top emission; no backside mirror; aperture < 3.7%;

CONCLUSION

- Micledi has developed a solution to integrate tight pitched (<3um) compound semiconductor with advanced 300mm Si-CMOS node for microLED arrays

- Proven process flow for passive 3µm pitch microLED array on 300mm full-automatic manufacturing tools (demo sample blue/green GaN LED available; blue GaN LED with wafer level optics Q3/2022; red GaN processing started)

- 300mm Foundry transfer started

- This work was done in collaboration between MICLEDI and imec. We would like to acknowledge 3D and SAT department of imec, Imec 300mm pilot line and MICLEDI team Leuven

- Authors would like to acknowledge VLAIO O&O funding "MICLEDI"