ADDING AN 'O' TO LEDS

STATUS AND PERSPECTIVES OF ORGANIC LIGHT EMITTING DIODES

PAWEL E. MALINOWSKI, TUNGHUEI KE

LIVING ROOM NOT SO LONG AGO...

Source: Warner Bros.

Source: Warner Bros.

LIVING ROOM NOW...

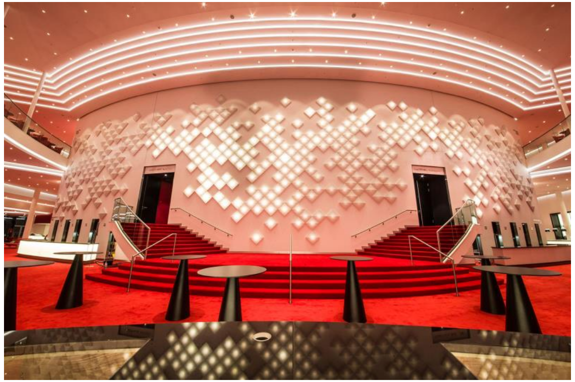
Source: Philips

Source: Philips

LIGHTING

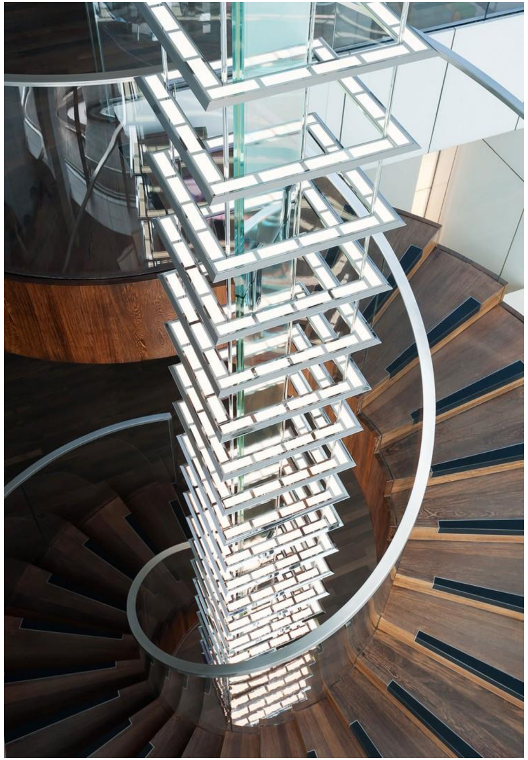
FROM BULBS TO PANELS
NEW FORM FACTORS FOR OLED LIGHTING

OLED LIGHTING: INSTALLATIONS



OLED Works

Sumitomo



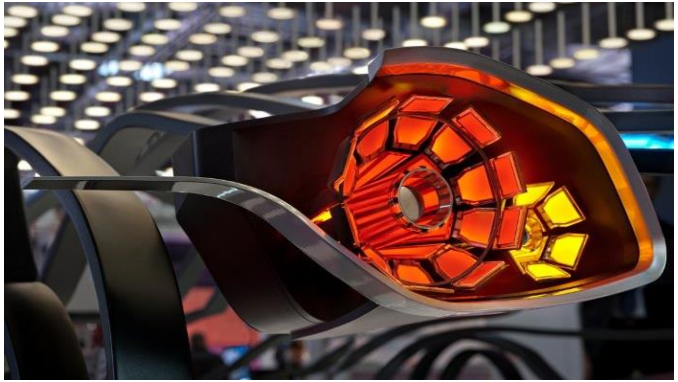
OSRAM

Konica Minolta

OLED Works

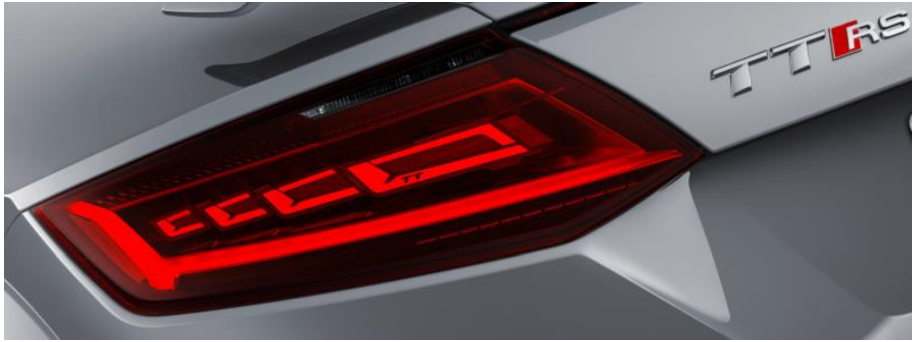
OLED LIGHTING: AUTOMOTIVE

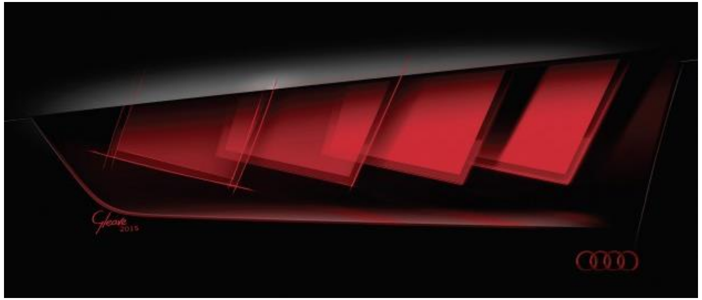
BMW M4



Astron Fiamm

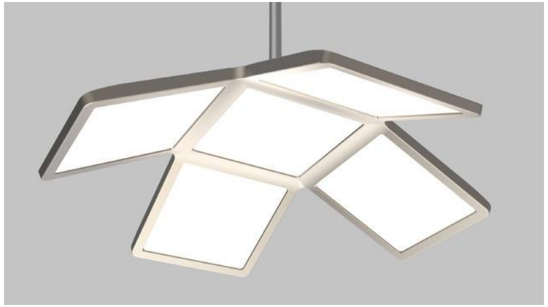
Audi TT RS





Audi

OLED LIGHTING: PANELS



Acuity

IKEA

LG Chem

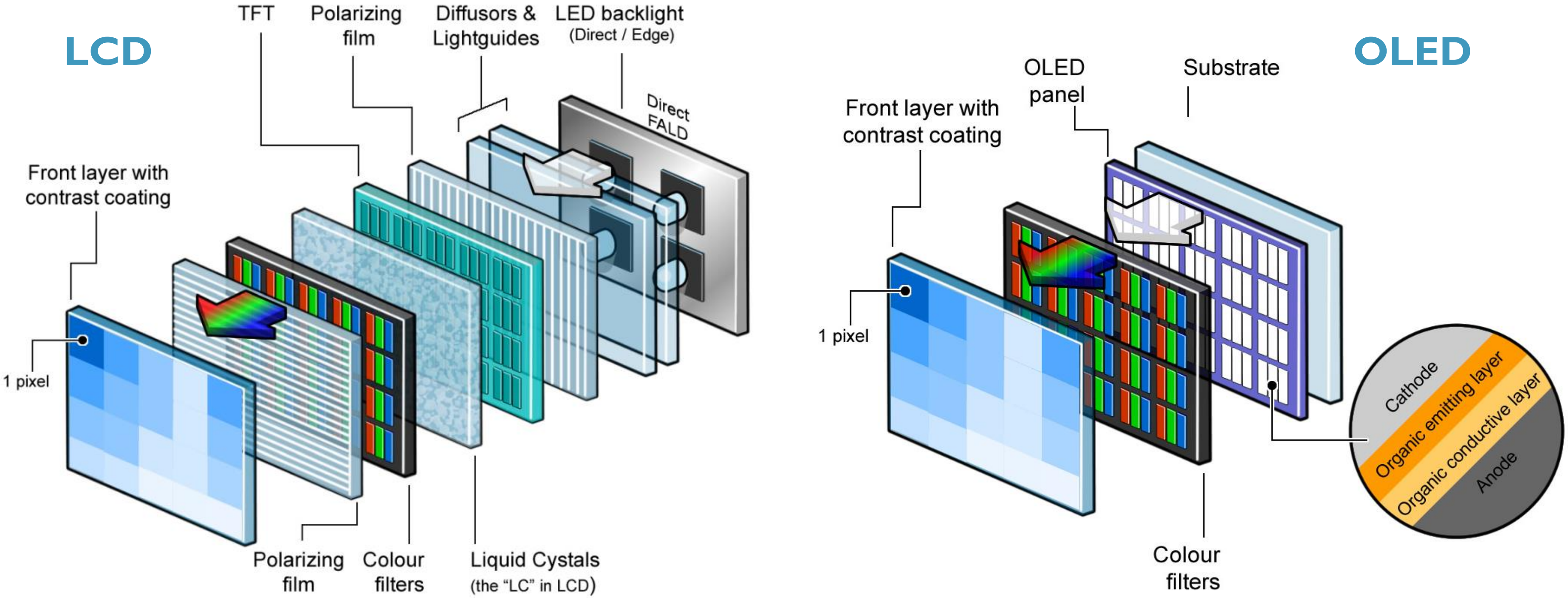
aerelight

LG Chem

DISPLAYS

LCD VS. OLED

~15 MM PANEL VS. ~5 MM PANEL



AMOLED DISPLAYS TODAY

BOE

Sharp

BOE

Apple/LG

Samsung

Tianma

AUO

AMOLED DISPLAYS: SMARTPHONE

LED EVENT 2017 BE 29-11-17 NL 30-11-17

Samsung

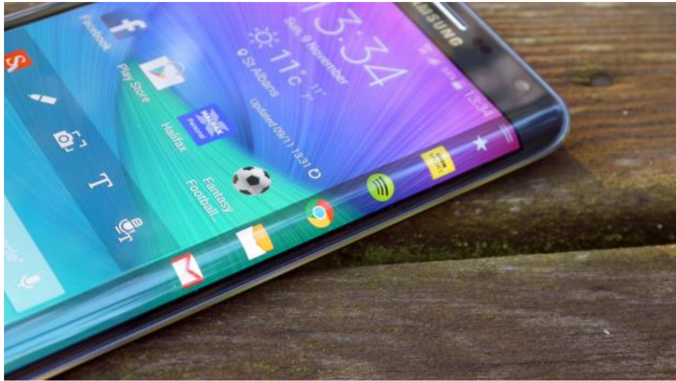
Apple

LG

Google

Huawei

Samsung



LED EVENT 2017 BE 29-11-17 NL 30-11-17

AMOLED DISPLAYS: TV

LG

Sony

LG

LG

Samsung

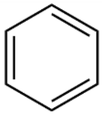
CURVED DISPLAYS

Source: LG Display

FLEXIBLE DISPLAYS

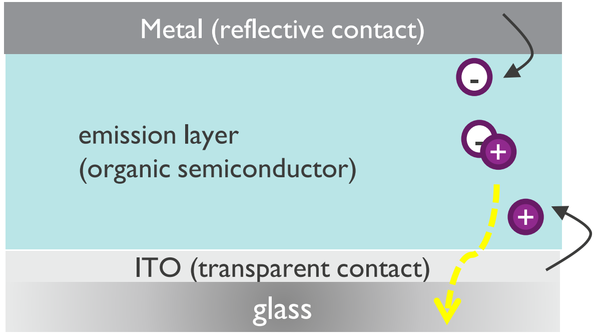
Source: *LG Display*

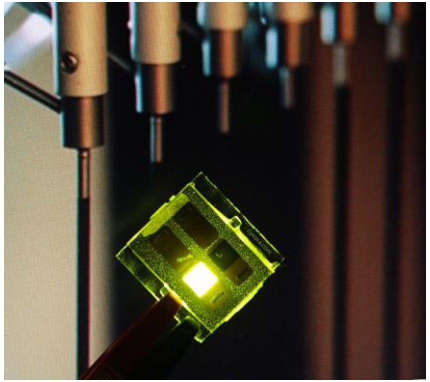
THE "O"



ORGANIC LIGHT EMITTING DIODES

ULTRA-THIN LAYERS EMITTING LIGHT



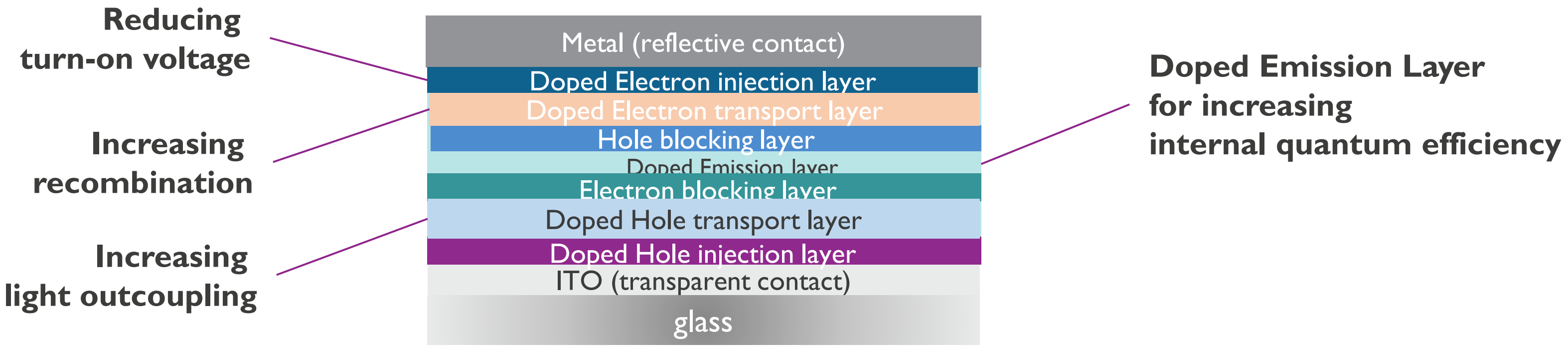


Organic semiconductor:
- small molecule → vacuum evaporation
- polymer → solution processing

First small molecule OLED in 1987
Tang et al in *Applied Physics Letters*
First polymer OLED in 1990
Burroughes et al in *Nature*

MODERN ORGANIC LED STRUCTURE FOR SINGLE COLOR

MORE EFFICIENT MULTILAYER OLED STRUCTURE



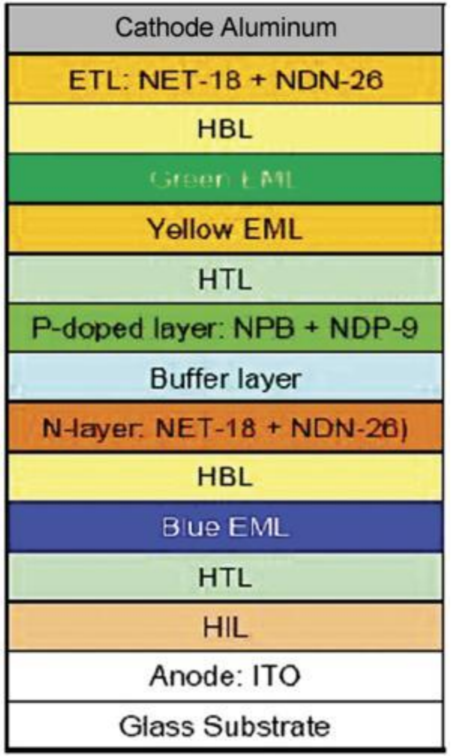
Single color OLED:

5-10 layers, 10-15 materials, 100-200 nm thick

MODERN ORGANIC LED STRUCTURE FOR WHITE

EVEN MORE LAYERS FOR EFFICIENT WHITE

Improved OLED structure:



tandem white OLED by Novaled

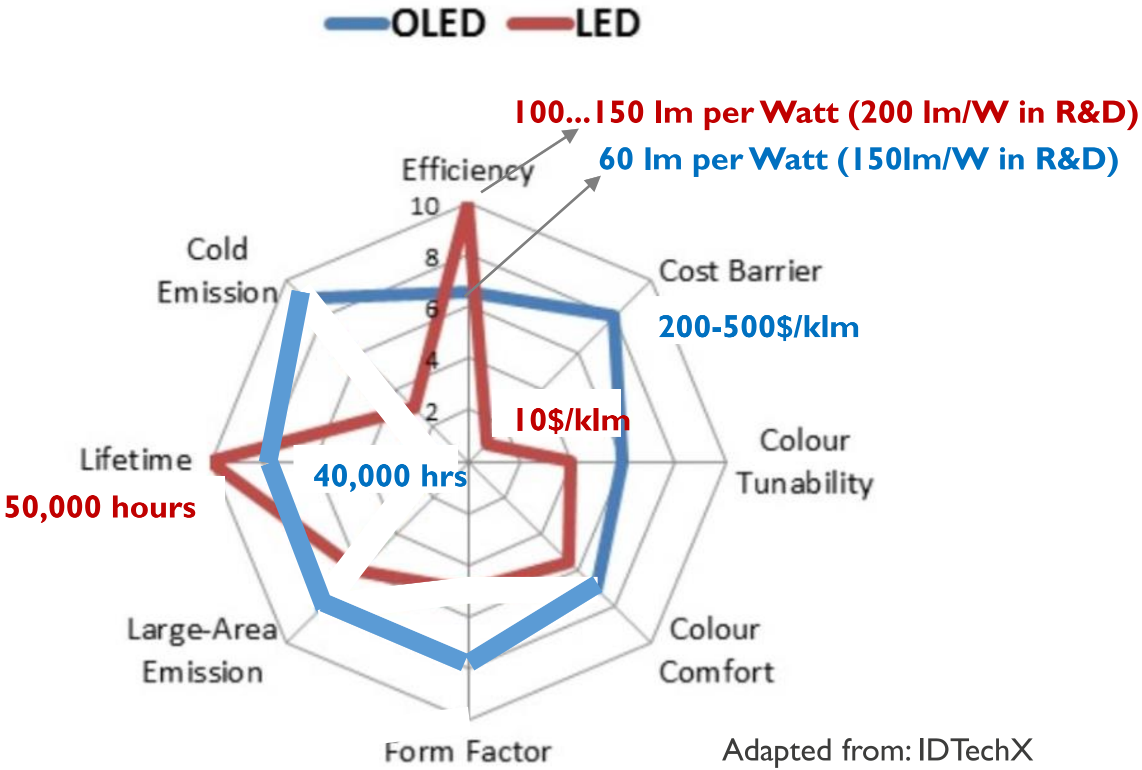
White OLED:

→ **stacking** different colors
Separate layer for phosphorescent red and green and for fluorescent blue

→ 8-15 layers, 20+ materials

OLED VS. LED

DIFFERENTIATOR IS TRANSPARENCY AND FLEXIBILITY



Adapted from: IDTechX

OLED PERFORMANCE

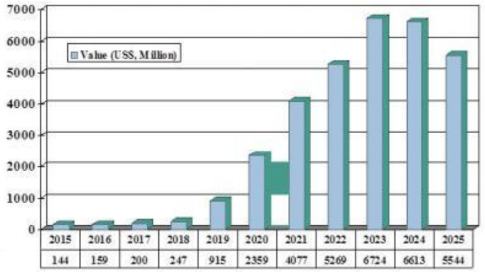
BRIGHTNESS AND EFFICIENCY REQUIREMENTS

- Brightness – depending on application:
  - lighting: 1000-2000 cd/m2 (more – better)
  - TV: 200 cd/m2
  - viewfinder: 200-300 cd/m2
  - smartphone: 500-800 cd/m2
  - augmented reality: 3000-5000 cd/m2 (not sufficient lifetime at present)
  - head up display in cars: 10k-20k cd/m2 (not sufficient lifetime at present)
- Efficiency – depending on brightness, color point, lifetime, operation condition, barrier, integration process flow:
  - red: 15-30 cd/A
  - green : 50-80 cd/A
  - blue: 5-15 cd/A

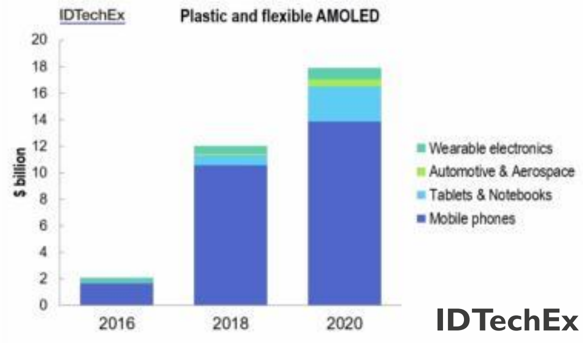
OLED LIGHTING MARKET

LARGE GROWTH ESTIMATED – BUT THE ESTIMATES SHIFT

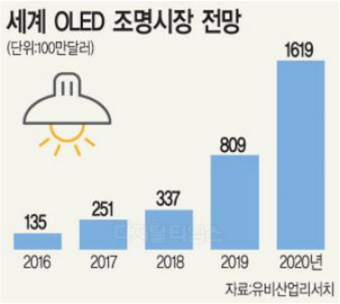
- **2014** IHS: market will grow tenfold by 2020 to reach $26 million
- **2015** Nanomarkets: $1 billion OLED lighting market in 2020
- **2015** ElectroniCast: to almost $2.4 billion in 2020 and $6.7 billion in 2023
- **2016** Yole Developpement: $1.5 billion OLED lighting market in 2021
- **2016** UBI: growth from $114 million to $1.6 billion by 2020
- **2017** UBI: OLED lighting market will reach $1.9 billion by 2021
- **2017** IDTechEx: OLED lighting market will reach $2.5 billion in 2027



ElectroniCast



IDTechEx



UBI

imec Holst Centre
Open Innovation by imec and TNO

IMEC & HOLST CENTRE

IMEC (LEUVEN, BE) / HOLST CENTRE (EINDHOVEN, NL)

imec

wafer fabs:
6 / 8 / 12 inch

Holst Centre
Open Innovation by imec and TNO

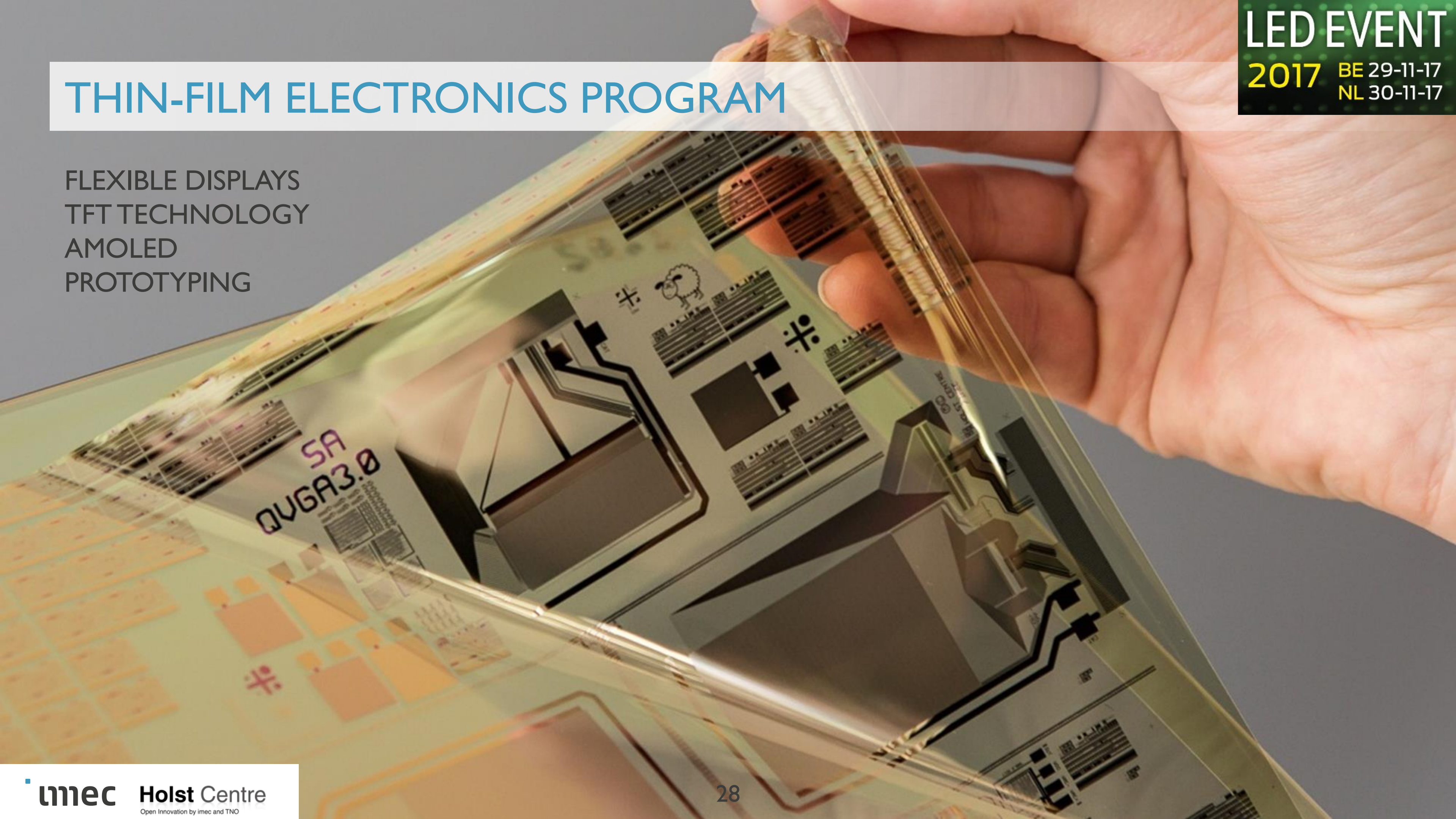
plate line:
GEN1 (35x32 cm)

IMEC: INDEPENDENT R&D HUB

NANOTECHNOLOGY
SINCE 1984
3500 PEOPLE
77 NATIONALITIES
>600 PARTNERS

THIN-FILM ELECTRONICS PROGRAM

FLEXIBLE DISPLAYS
TFT TECHNOLOGY
AMOLED
PROTOTYPING



R&D ON DEMAND

PROTOTYPING FACILITY FOR THIN-FILM ELECTRONICS

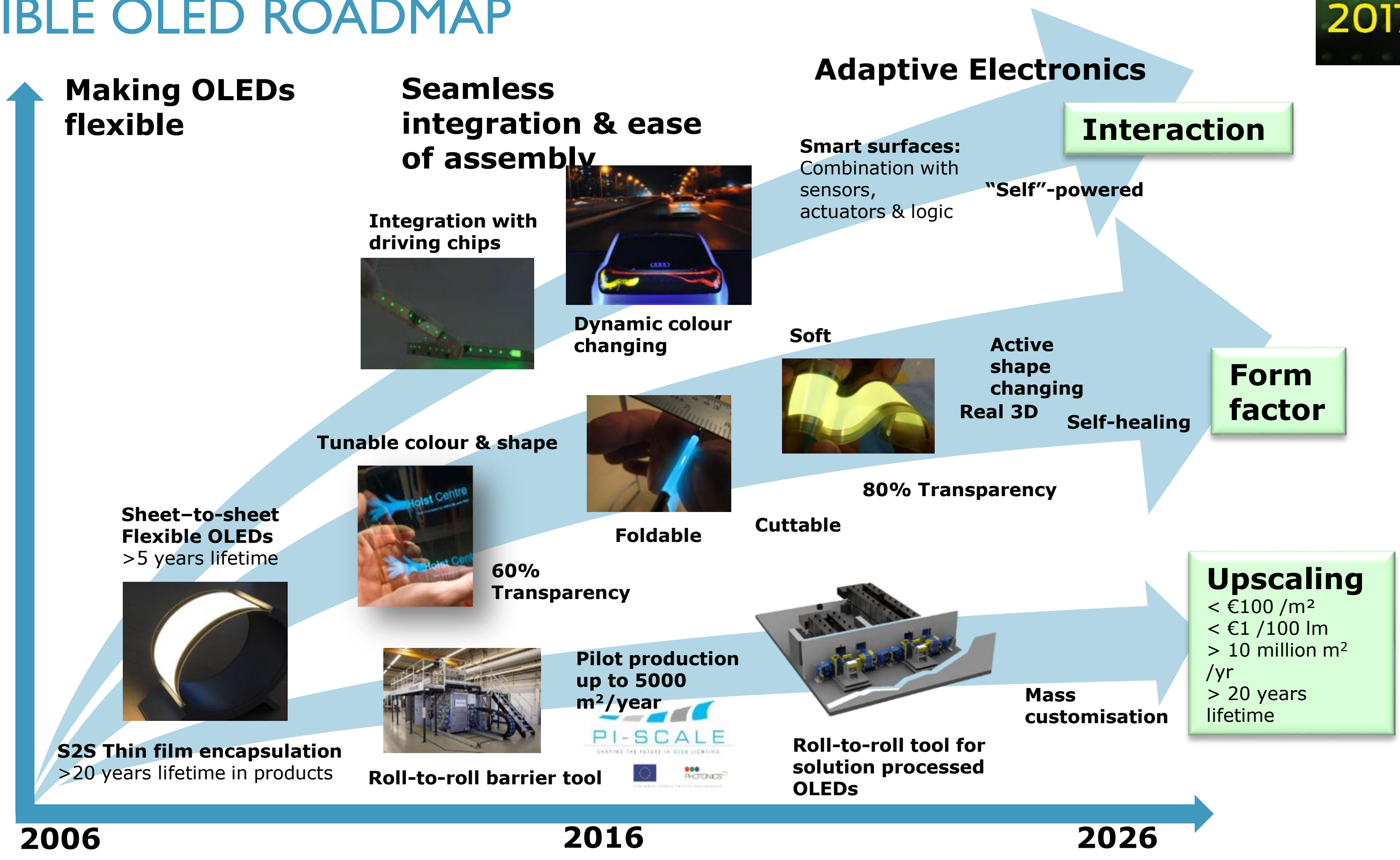
- From fundamental research to tech transfer
- Collaboration in shared and dedicated projects
- 6 inch and Gen 1 (350x320 mm^2) lines
- FPD compatible processes
- Low-volume:100-10,000 components

OLED LIGHTING @ HOLST CENTRE

Holst Centre

Open Innovation by IMEC and TNO

FLEXIBLE OLED ROADMAP



VISION FOR FLEXIBLE OLED INTEGRATION

80% transparent or imperceptible

3D ultra-thin shapeable or stretchable form to seamlessly follow contours

PROTOTYPE OF FLEXIBLE OLED INTEGRATION INTO CAR CONSOLE UNIT

IN-MOLD ELECTRONICS

Capacitive slider

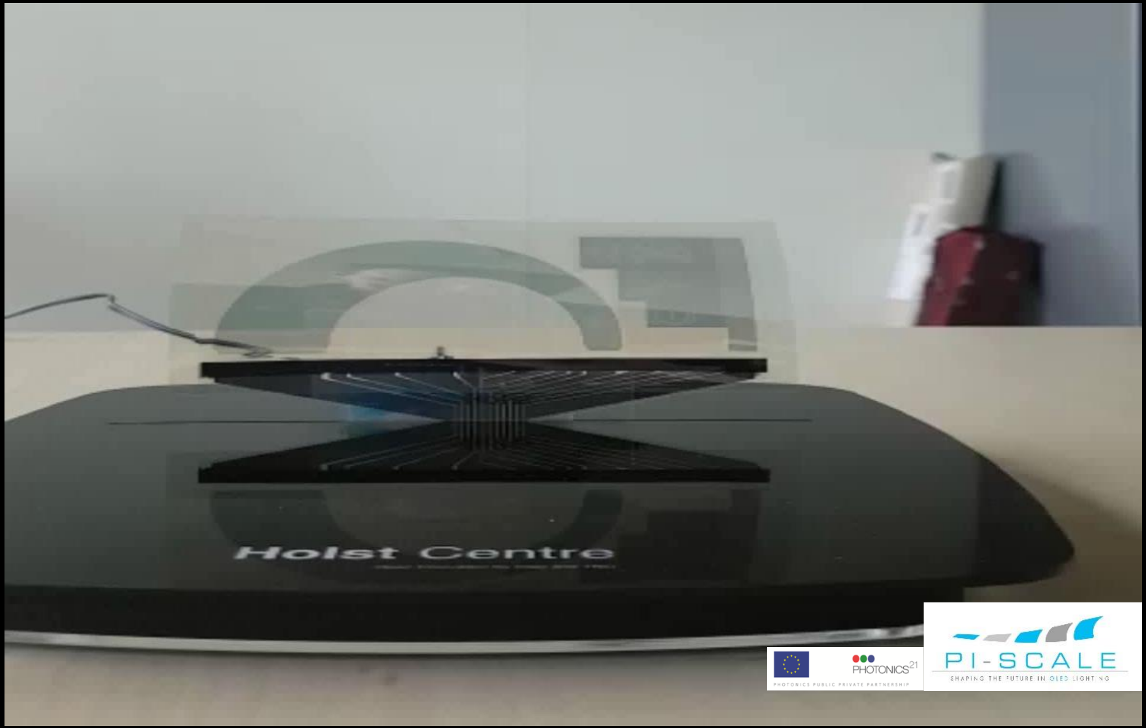
Illumination with OLEDs

Capacitive buttons

Integrated NFC antenna

WIRELESS CONTACT OF FLEXIBLE OLED LIGHTING AND SIGNAGE

TRANSPARENT FLEXIBLE OLED SIGNAGE FILM IN AUTOMOTIVE DEMONSTRATOR



OLEDS WITH A SOFT FORM FACTOR

FLEXIBLE ROLL-TO-ROLL OLEDS

Holst Centre R2R moisture barrier film
Fraunhofer FEP R2R ITO + R2R evaporated OLED

1.8 m x 30 cm
(15 m made in each run)

AMOLED DISPLAYS @ HOLST CENTRE

Holst Centre

Open Innovation by IMEC and TNO

FUTURE MIXED REALITY DISPLAYS

Hi-Res TFT backplane
Hi-Brightness OLEDs
Efficient data processing
Sensors (e.g. eye-tracking)
User interface (haptic feedback)
Power management

photo: Shutterstock

OLED DISPLAYS @ HOLST CENTRE

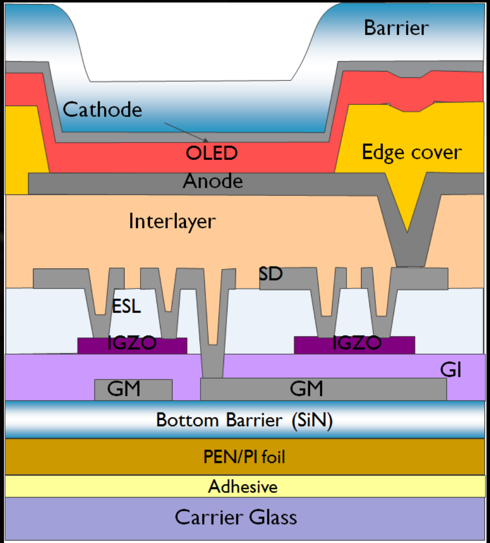
Holst Centre

Open Innovation by IMEC and TNO

IMEC/HOLST AMOLED DISPLAYS

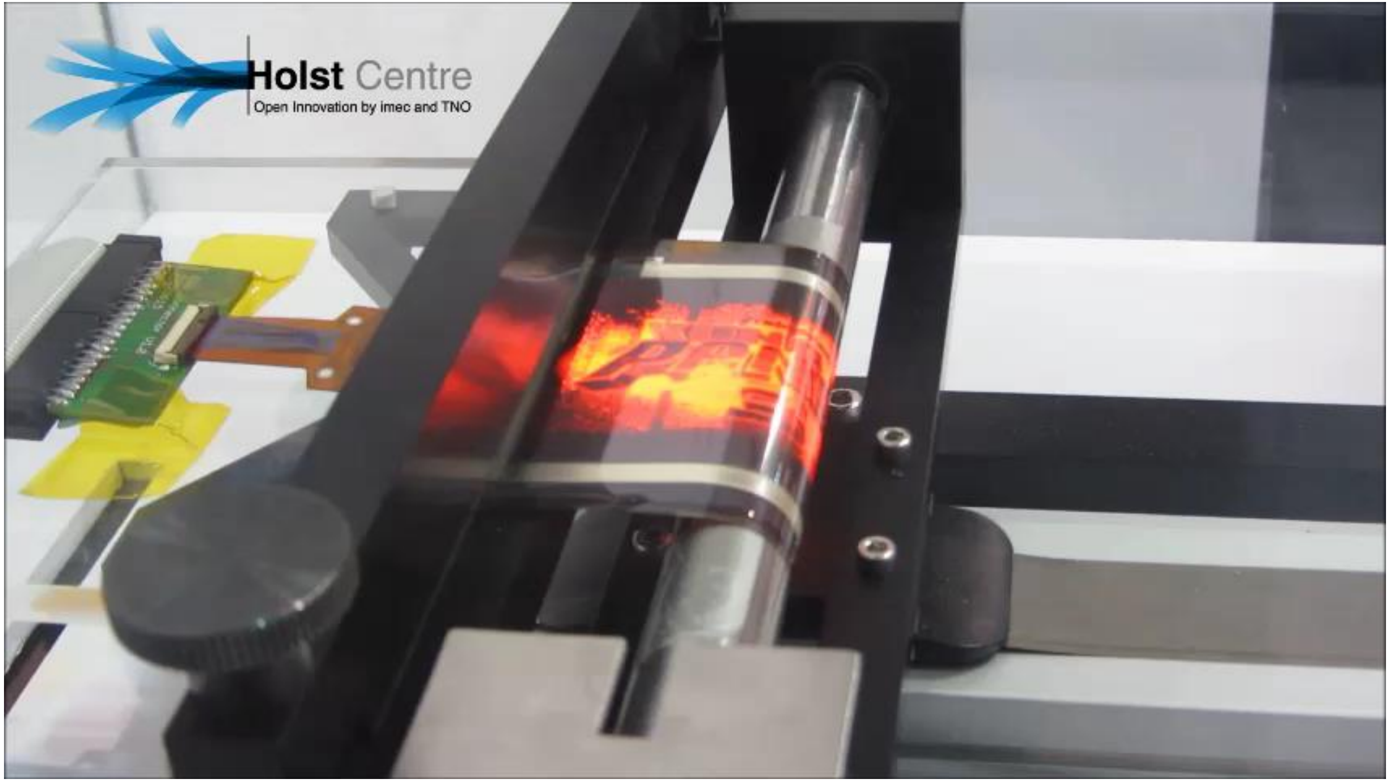
IGZO backplane
OLED frontplane
GEN1 substrate
165 process steps

Diagonal	4.0 inch
Resolution	QVGA, 320 ppi
Pixel Circuit	2T1C
OLED Type	Top-Emission
Display Driving	IC / in-panel
Substrate	PEN or PI



Holst Centre 2014

IMEC/HOLST DEMO AT TOUCH TAIWAN 2015



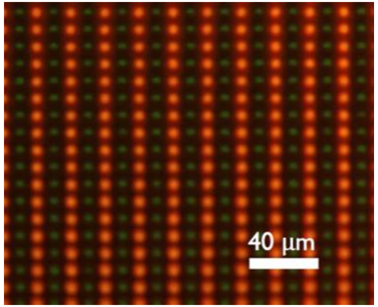
1250 PPI 2-COLOR PASSIVE OLED DISPLAY

TOUCH TAIWAN 2017 DEMO

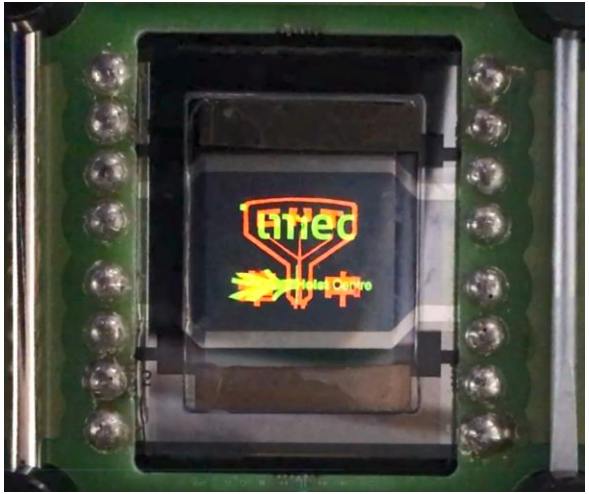
Only 1st color

Only 2nd color

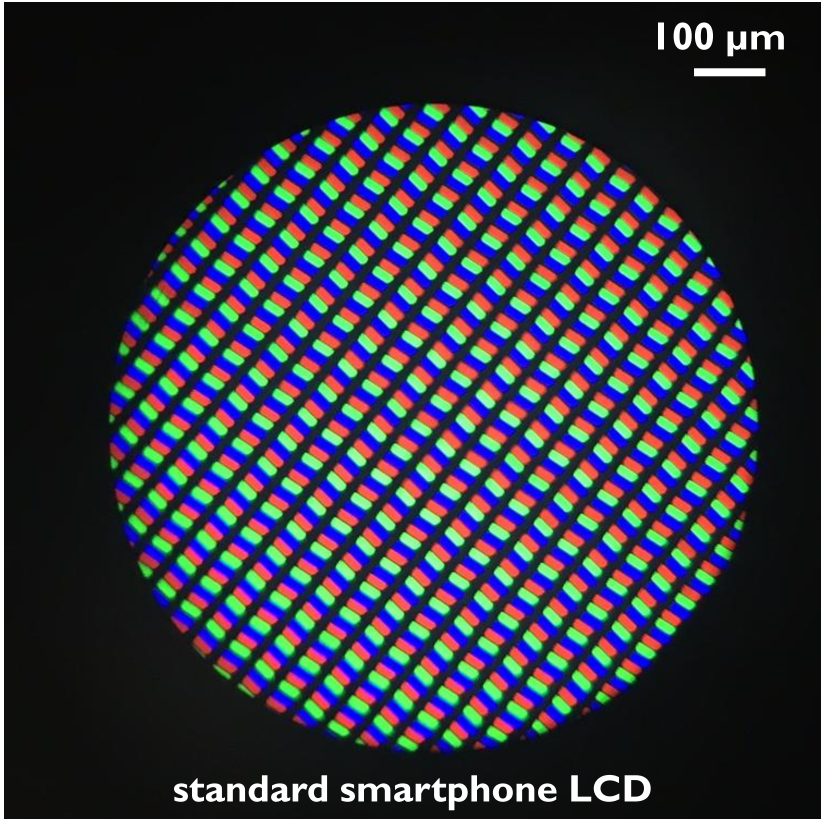

1st and 2nd color together

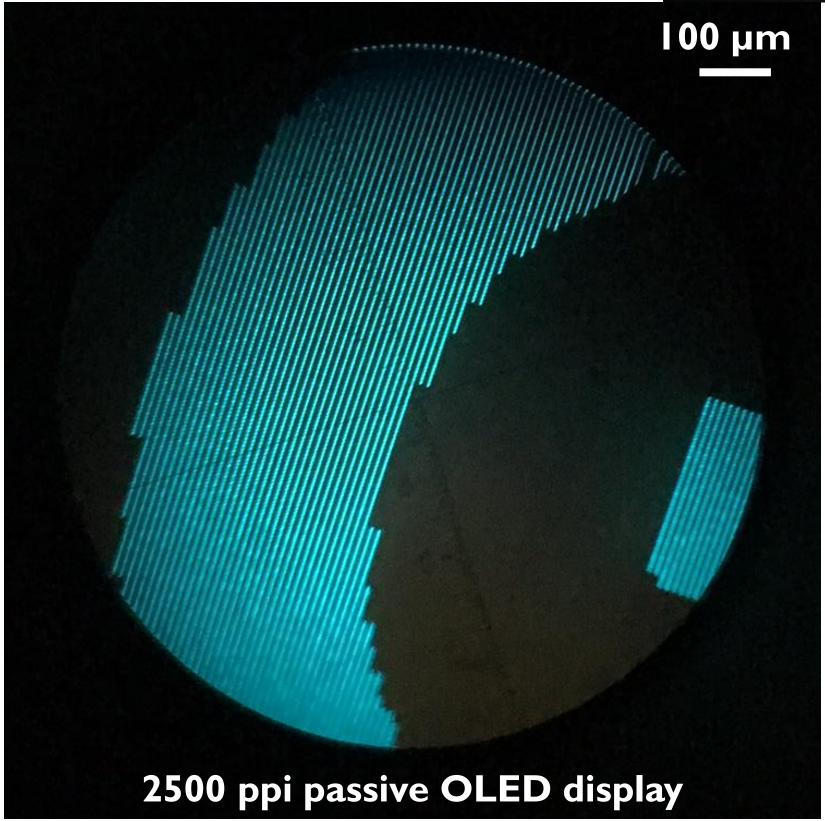


Zoom of the array


Display video

PASSIVE OLED DISPLAY DEMO





SUMMARY

THE "O" IN LEDS
SUMMARY

- OLEDs are here to stay
  - market getting larger and healthier
  - improvements still needed in TRL and MRL

- OLED R&D platform at Holst Centre
  - from screening materials, through process development and prototyping to fab transfer
  - international collaborations from academia to industry

embracing a better life

IMEC / HOLST ORGANIC PATTERNING TRACK RECORD

- P.E. Malinowski et al. "Photolithography as enabler of AMOLED displays beyond 1000 ppi", paper 44.1 (invited talk), SID Display Week, Los Angeles, 2017.
- T.H. Ke et al. "Effect of Integrated Protection Layer on Photolithographic Patterned OLED stack," 23rd International Display Workshops, IDW'16, Fukuoka, JP, 2016.
- P.E. Malinowski et al. "Multicolor 1250-ppi OLED Arrays Patterned by Photolithography", paper 74.3, SID Display Week, San Francisco, 2016.
- P.E. Malinowski et al. "Organic Photodetectors with Active Layer Patterned by Lithography", IEEE Sensors 2015, Busan, KR, 2015.
- T.H. Ke et al. "High aperture ratio organic light emitting diodes (OLED) pixels with 640 ppi resolution realized by CA i-line photolithography", 22nd International Display Workshops, IDW'15, Otsu, JP, 2015.
- P.E. Malinowski et al. "Patterning of multicolor OLEDs with ultra-high resolution by photolithography", paper 16.3, SID Display Week, San Jose, 2015.
- P. E. Malinowski et al. „Photolithographic patterning of organic photodetectors with a non-fluorinated photoresist system," Organic Electronics 15 (10), 2014
- P.E. Malinowski et al. "Patterning of multicolor OLEDs with ultra-high resolution by photolithography", 21st International Display Workshops, IDW'14, Niigata, JP, 2014 (Best Paper Award).