SMALL PITCH, HIGH RESOLUTION – SCALING OF OLED DISPLAYS

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Holst Centre
Open Innovation by IMEC and TNO

IWFPE 2016, JEONJU, KR

DISPLAY TRENDS

LARGE-AREA DISPLAYS

Source: Samsung Display

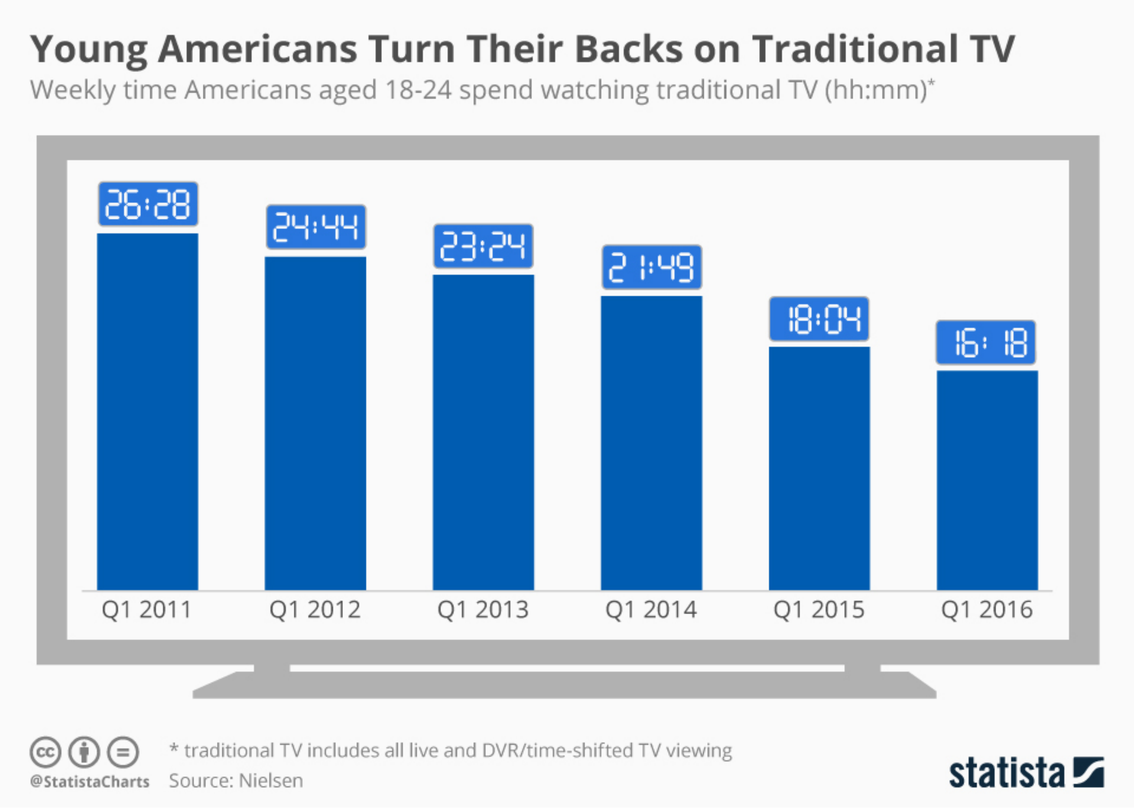
CURVED DISPLAYS

Source: LG Display

FLEXIBLE DISPLAYS

Source: *LG Display*

CONTENT MOVES TO MOBILE



* traditional TV includes all live and DVR/time-shifted TV viewing
Source: Nielsen

Source: Statista

MOBILE IS THE NEW INFORMATION PLATFORM

Source: Twitter

AUGMENTED REALITY

Source: *Niantic*

AUGMENTED REALITY

Source: FlightRadar24

AUGMENTED REALITY

Source: Volvo

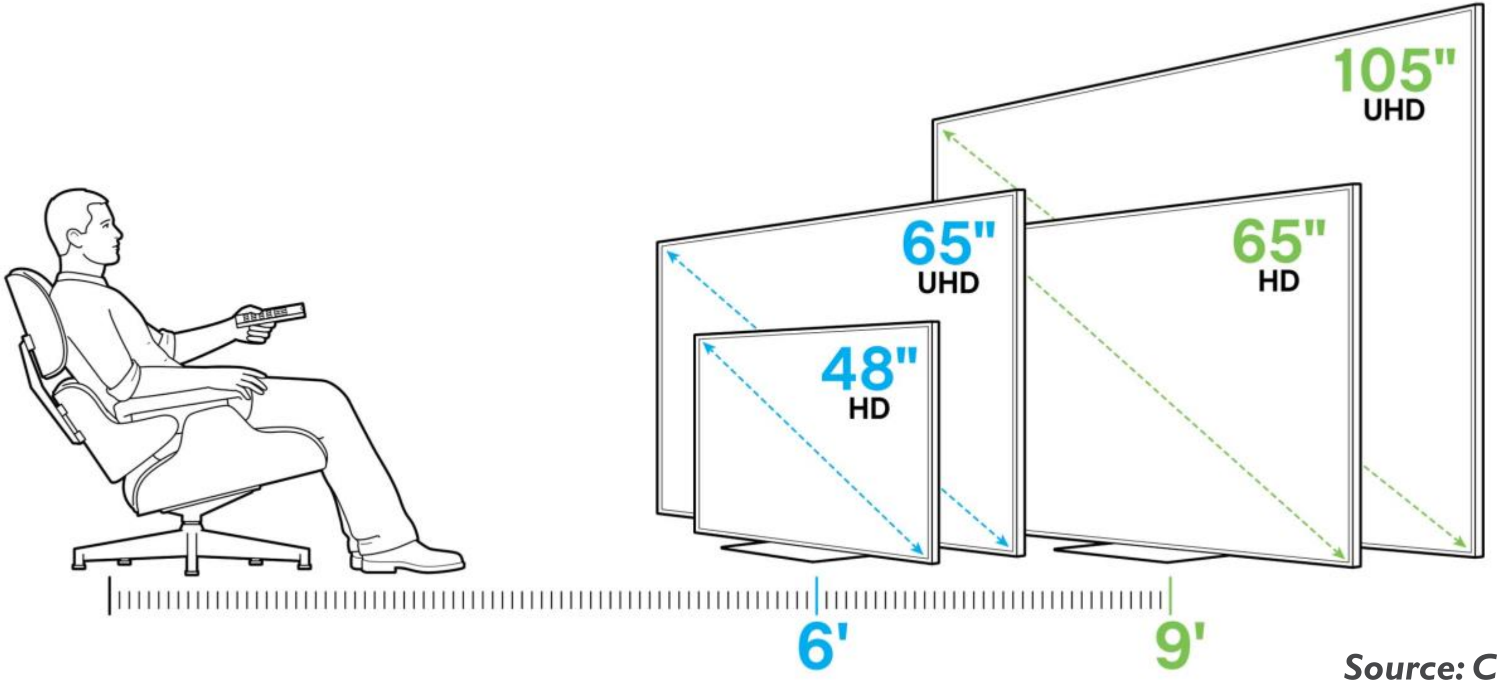
VIRTUAL REALITY

Source: Samsung Display

COMMON REQUIREMENT:
SMALL PITCH, HIGH RESOLUTION

HIGH RESOLUTION BENEFITS

SHORTER VIEWING DISTANCE WITH UHD



Source: Consumer Reports

HIGH RESOLUTION BENEFITS

"NATURAL 3D" FEELING

- sufficiently high resolution (8K) results in stronger depth sensation

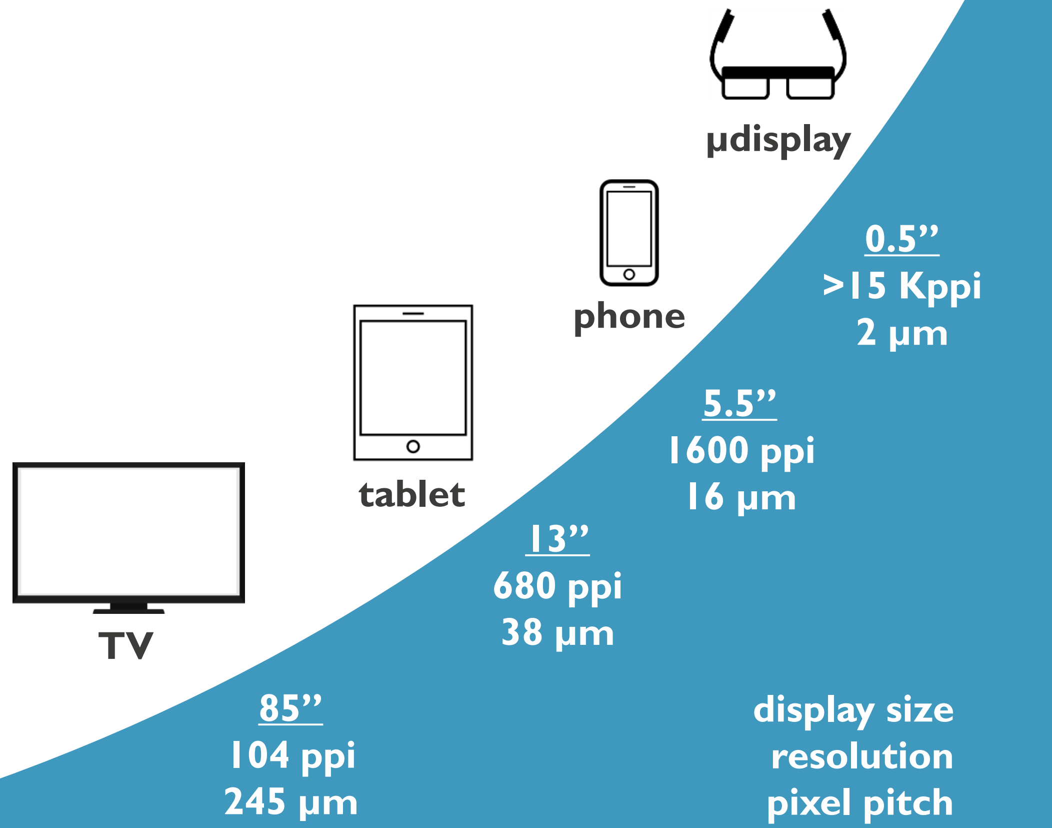
  ref:Tsushima et al., IDW'14 (VHF6-4L)
- enabler for glass-free 3D

HOW SMALL ARE PIXELS IN 8K DISPLAYS?

PIXELS GETTING SMALLER

- 245 µm pitch for 85 inch TV
- 16 µm pitch for 5.5 inch smartphone
- 2 µm pitch for microdisplay

8K



TV

85”
104 ppi
245 µm

tablet

13”
680 ppi
38 µm

phone

5.5”
1600 ppi
16 µm

µdisplay

0.5”
>15 Kppi
2 µm

display size
resolution
pixel pitch

imec Holst Centre
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SMARTPHONE DISPLAY EVOLUTION

RESOLUTION INCREASING ABOVE 800 PPI

- important for smartphone VR goggles
- 800 ppi desired for CJK characters
- difficult to go over 1000 ppi

Apple
iPhone 7 Plus
LCD
5.5 inch
401 ppi

Huawei
P9
LCD
5.2 inch
423 ppi

Google
Pixel XL
AMOLED
5.5 inch
534 ppi

HTC
One M9+
LCD
5.2 inch
565 ppi

Samsung
Galaxy S7
AMOLED
5.1 inch
577 ppi

Sony
Xperia Z5 Premium
LCD
5.5 inch
806 ppi

Sharp
prototype
panel
1008 ppi

PPI

HEAD-MOUNT DISPLAY EVOLUTION

SMARTPHONE VS. MICRODISPLAY GOGGLES

- high aperture ratio (no “screen-door effect”)
- > 1000 ppi resolution
- gap between panels and microdisplays

Sony
PS VR
OLED
386 ppi

Oculus
Rift CV1
OLED panels
455 ppi / eye

HTC
Vive
OLED panels
455 ppi / eye

Samsung
Gear VR + GS7
µdisplay
577 ppi

Sharp
prototype
panel
1008 ppi

eMagin
WUXGA Color XL
µdisplay
2630 ppi

MicroOLED
SXGA RGBW
µdisplay
2687 ppi

PPI

FPD PANEL

MICRODISPLAY

AUGMENTED REALITY EVOLUTION

IMAGE ON TOP OF WORLD VIEW

- high brightness (>> 1000 nit)
- maximum transparency
- lower field-of-view needed than in VR

Fraunhofer
prototype
µdisplay
320x240 px

Google
Glass
µdisplay
640x360 px

Vuzix
M300
µdisplay
640x360 px

Solos
Vista
µdisplay
640x360 px

Microsoft
HoloLens
'light engine'
1268x720 px / eye

Epson
Moverio BT-300
µdisplay
1280x720 px

AR DEVICES RESOLUTION

COMPONENTS FOR NEXT-GEN DISPLAYS

- **8K resolution** → natural 3D; large viewing angle
- **high aperture ratio** → no “screen-door effect”
- **transparency** → augmented reality
- **high brightness** → outdoor viewing
- **low power** → wearable electronics
- **flexible substrates** → portability; light weight

- **AMOLED**

AMOLED DISPLAYS AT IMEC / HOLST

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

imec

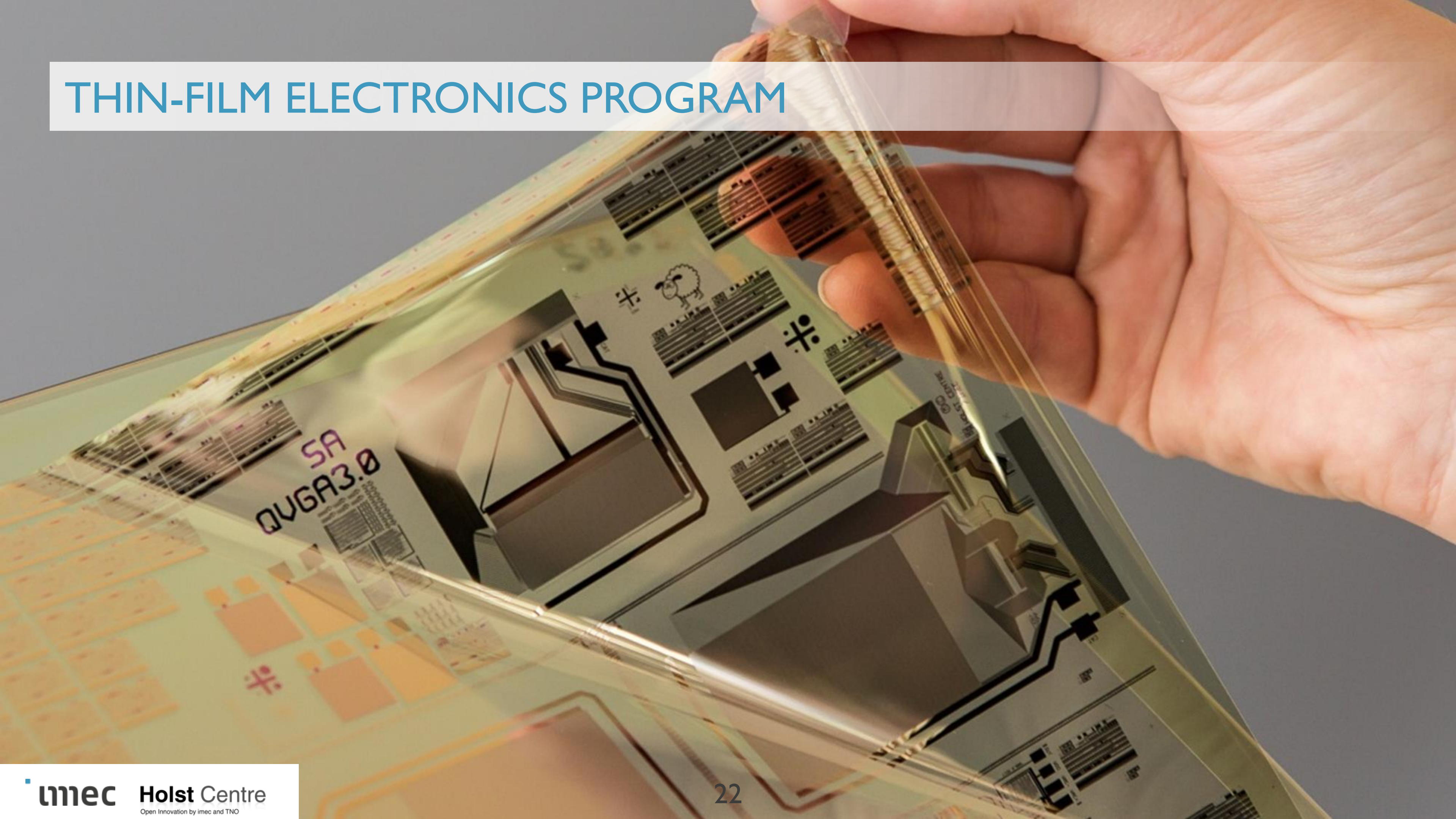
3500 people

Holst Centre

Open Innovation by imec and TNO

200 people

THIN-FILM ELECTRONICS PROGRAM

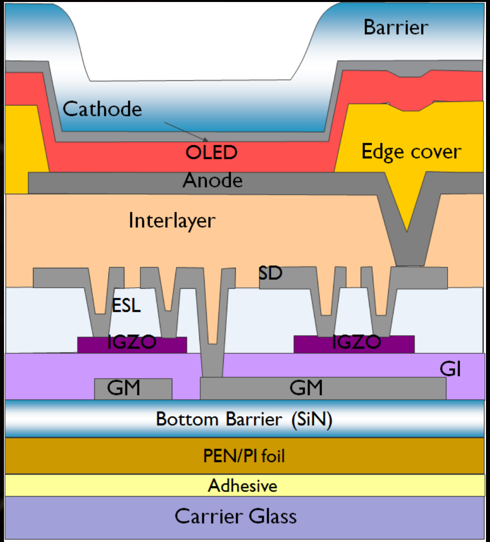


IMEC/HOLST AMOLED DISPLAYS

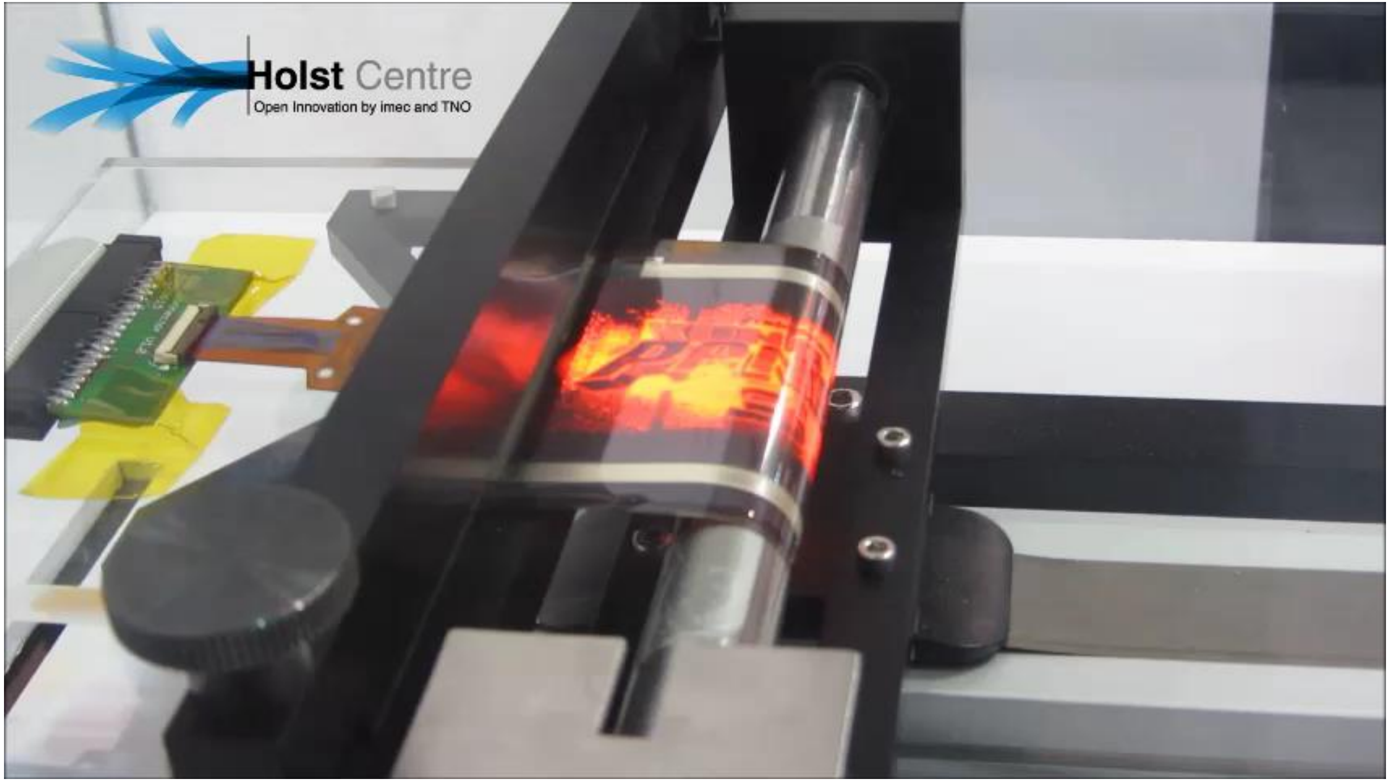

Holst Centre 2014

IGZO backplane
OLED frontplane
GEN1 substrate
165 process steps

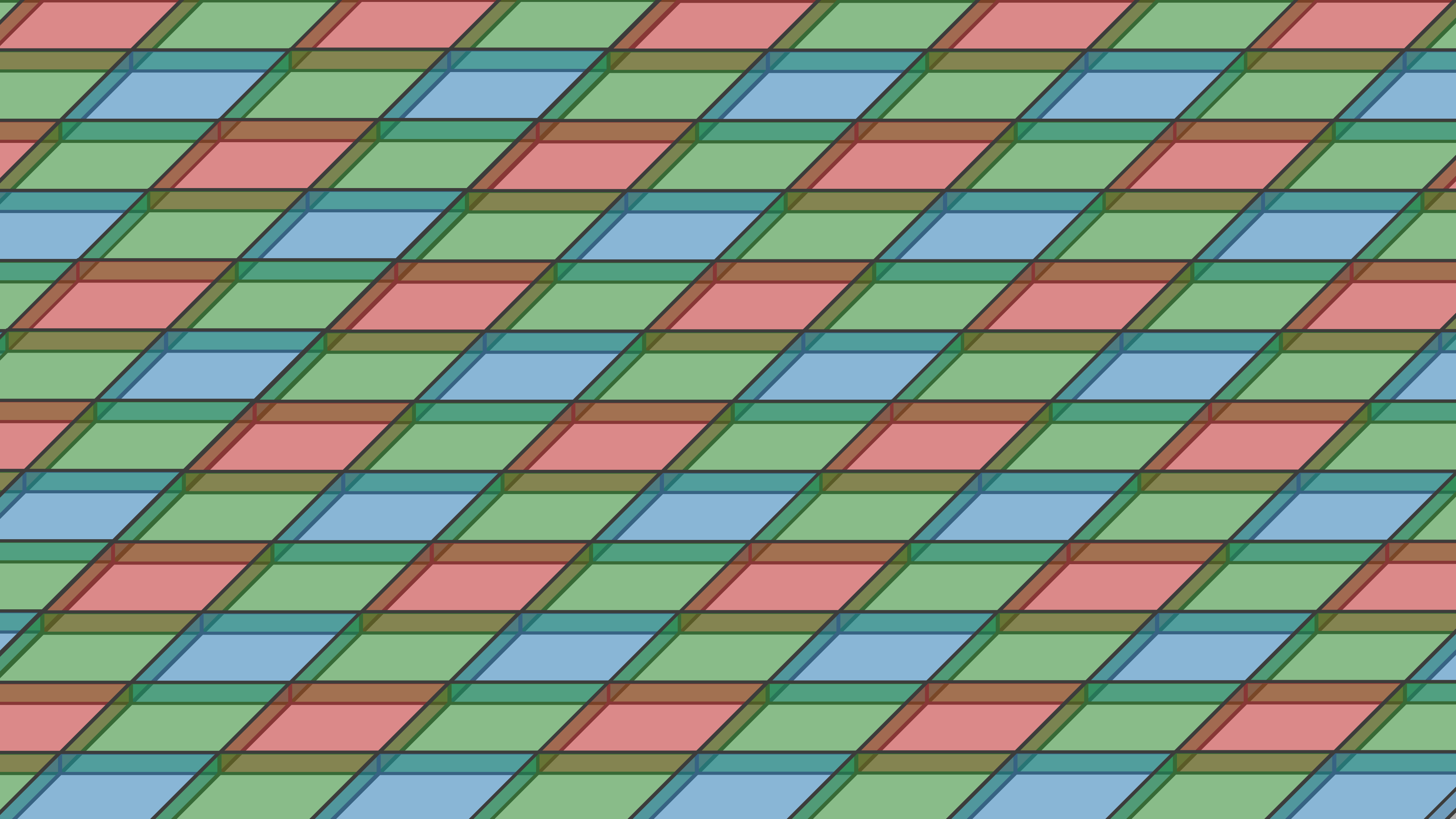
Diagonal	4.0 inch
Resolution	QVGA, 320 ppi
Pixel Circuit	2T1C
OLED Type	Top-Emission
Display Driving	IC / in-panel
Substrate	PEN or PI

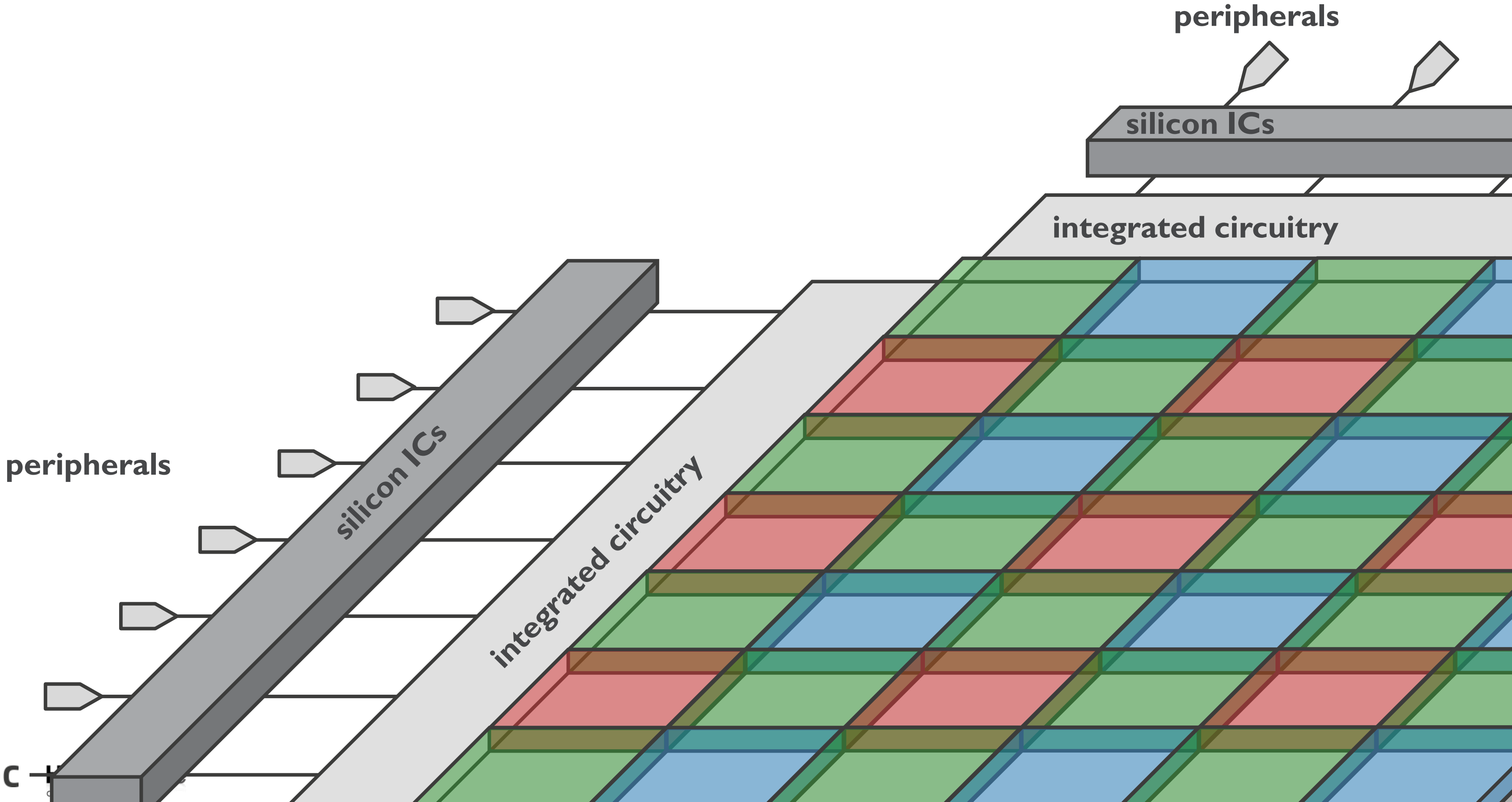


IMEC/HOLST DEMO AT TOUCH TAIWAN 2015



SCALING AMOLED DISPLAYS





peripherals

silicon ICs

integrated circuitry

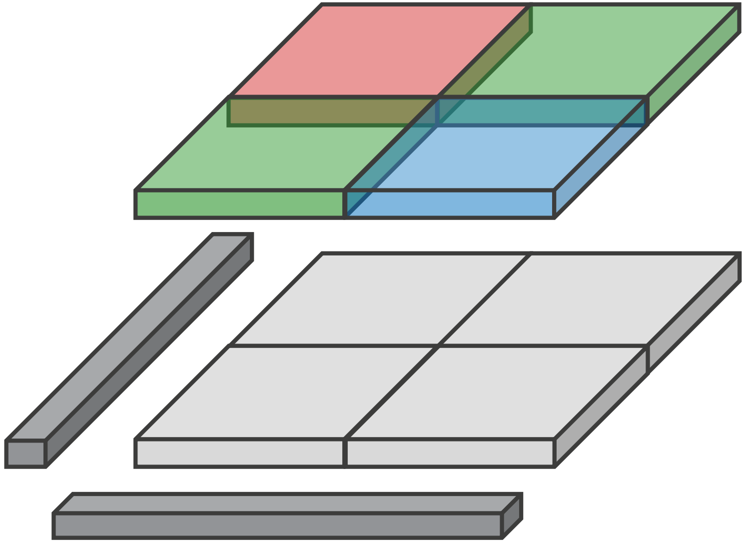
peripherals

silicon ICs

integrated circuitry

TOWARDS HIGHER PIXEL DENSITY

IMPROVEMENTS IN 3 AREAS:

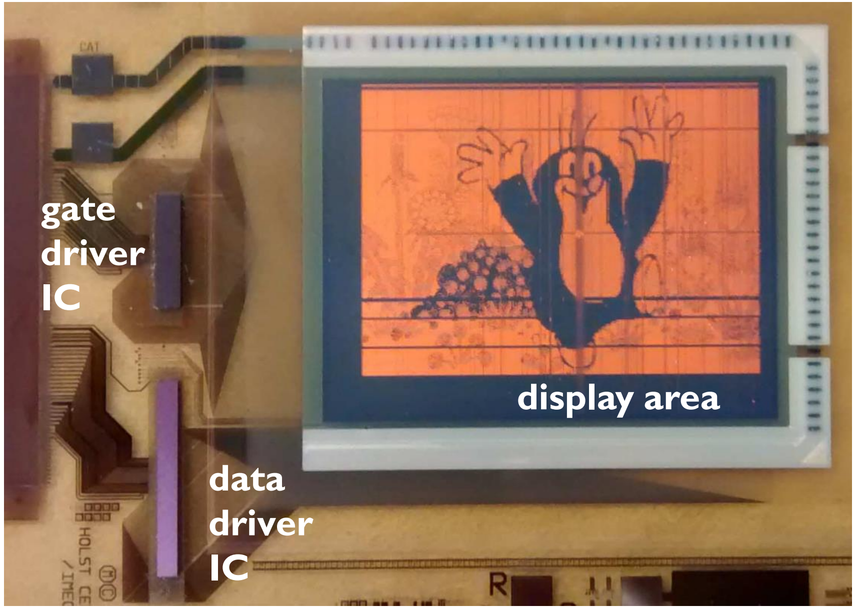


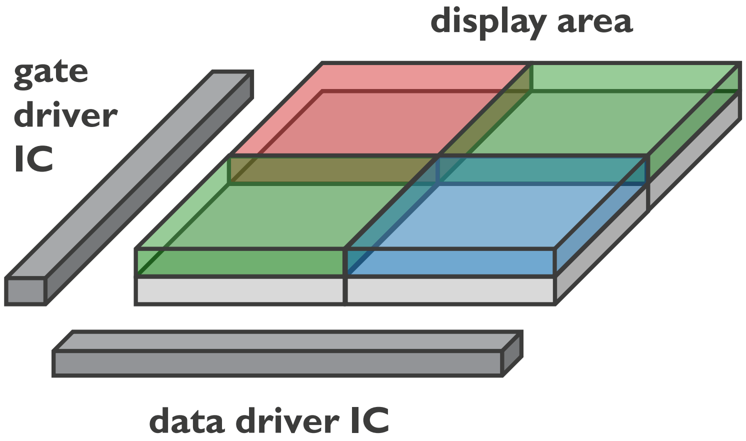
FRONTPLANE	**RGB resolution** **higher aperture ratio**
BACKPLANE	**better semiconductors** **compact architectures** **process resolution**
DRIVING	**integrated drivers** **PWM scheme**

DRIVING SCHEMES

DRIVING AMOLED DISPLAYS

DISPLAY + EXTERNAL DRIVER CHIPS

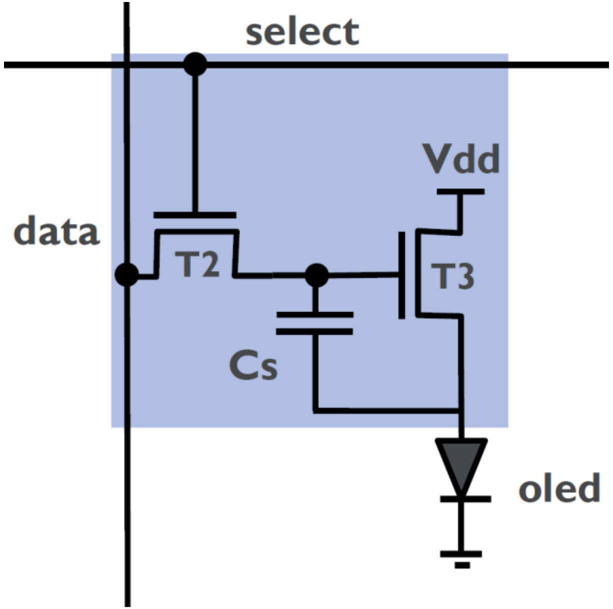




DRIVING SCHEMES

NEW PIXEL ENGINES

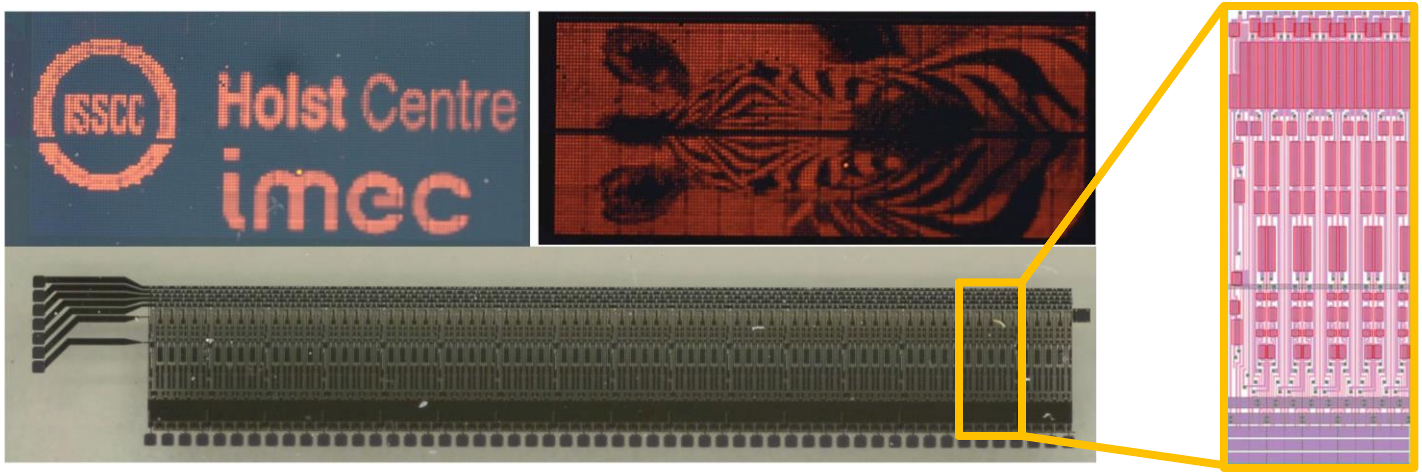
- current driving needed for OLEDs
  - compensation necessary
  - current pixel design: > 4T
  - difficult to squeeze in 1000 ppi backplanes
- simpler pixels needed
  - scalable 2T1C or 3T2C
  - compensation moves off-backplane



DRIVER INTEGRATION

IN-PANEL GATE DRIVER

- New gate drivers:
  - preferably integrated 'in panel'
  - adapted to new driving schemes



Jan Genoe et al., ISSCC 2014

NEW OLED DISPLAY DRIVING SCHEMES

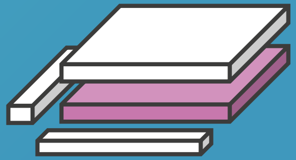
COMBINING HIGH RESOLUTION WITH COMPENSATIONS

- PWM: radically different way to feed the data
  - OLED has 100% duty cycle, no OLED overdrive for full brightness
- Split the most significant bits over multiple subframes
  - No motion artifacts
- Current comes from silicon ICs
  - Accurate light output, allowing 16 bit grey levels
- Compensation for TFT/OLED non-uniformity and degradation possible
  - Using sporadic calibration scans
  - Corrections happen in the driver ⇒ simple pixels
- Transistor used as a switch in the linear region
  - Lowers power consumption (power loss in TFT can be minimized)

1. **Pulse Width Modulation**

⇩

2. **Digital Current Driving**

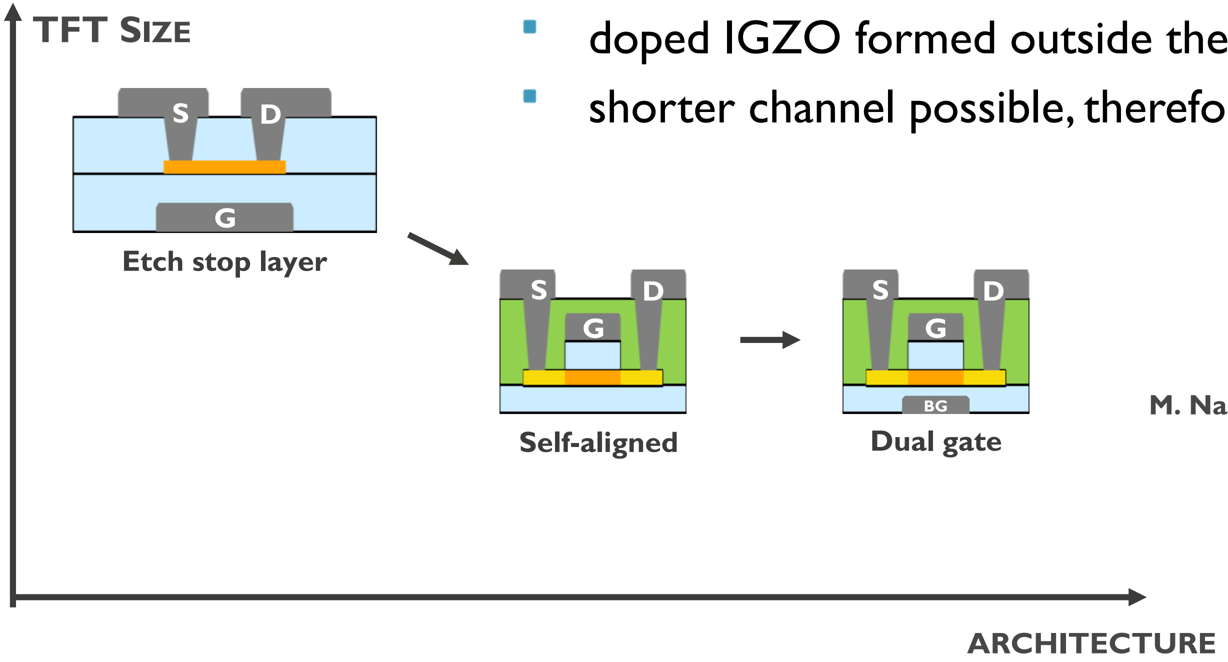


TFT BACKPLANE

TFT ARCHITECTURES

SA TFT ENABLES MORE COMPACT FOOTPRINT

- less parasitics in self-aligned TFT
- doped IGZO formed outside the gate area
- shorter channel possible, therefore smaller footprint

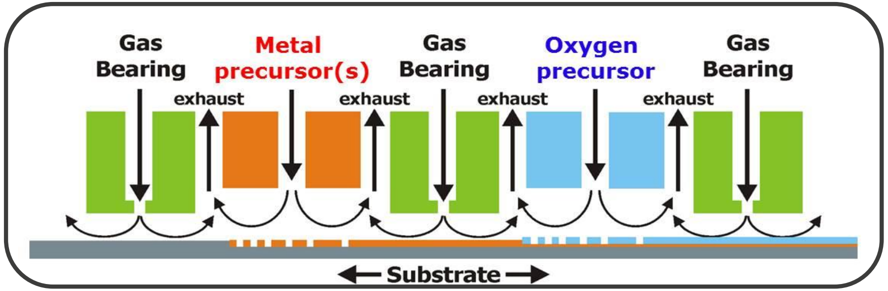


M. Nag et al., SID2015

NEW SEMICONDUCTORS

SPATIAL ALD ENABLES HIGH QUALITY IZO TFTS

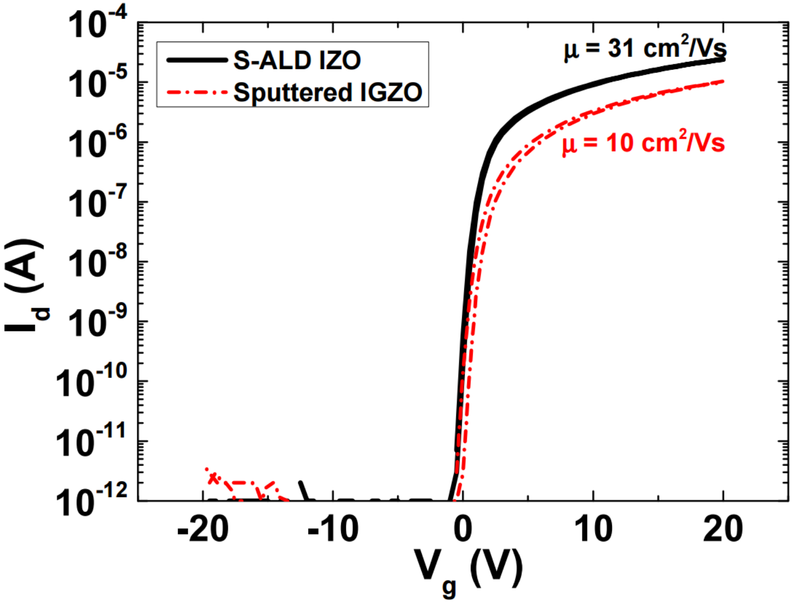
- spatial separation of half reactions instead of time-separated
- deposition rate > 1 nm/s at atmospheric pressure



NEW SEMICONDUCTORS

SPATIAL ALD ENABLES HIGH QUALITY IZO TFTS

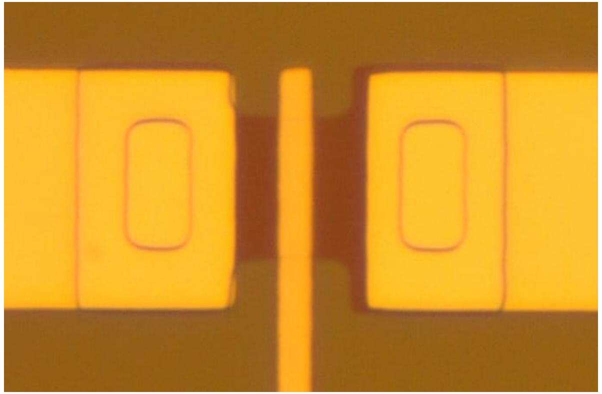
- IZO with mobility 30 cm^2/Vs – above IGZO



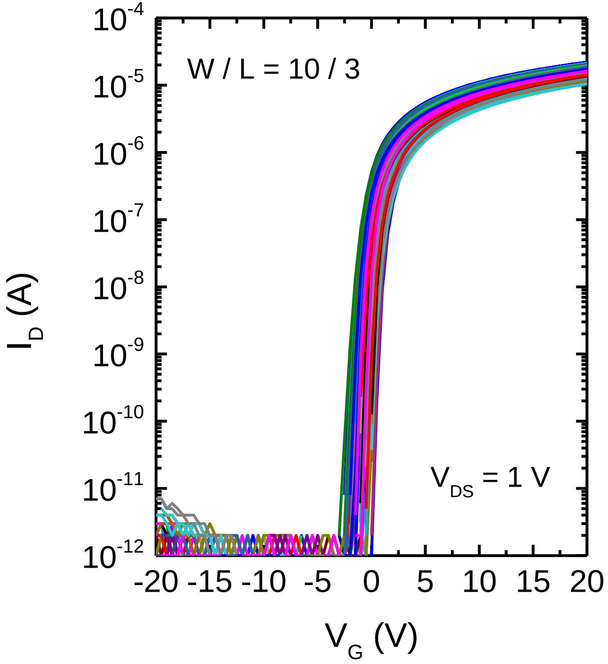
MINIMUM FEATURE SIZE

LIMITED BY TOOLS' RESOLUTION AND ACCURACY

- good uniformity over GEN1 plate down to 3 µm channel length
- standard FPD tools limited to 1 µm

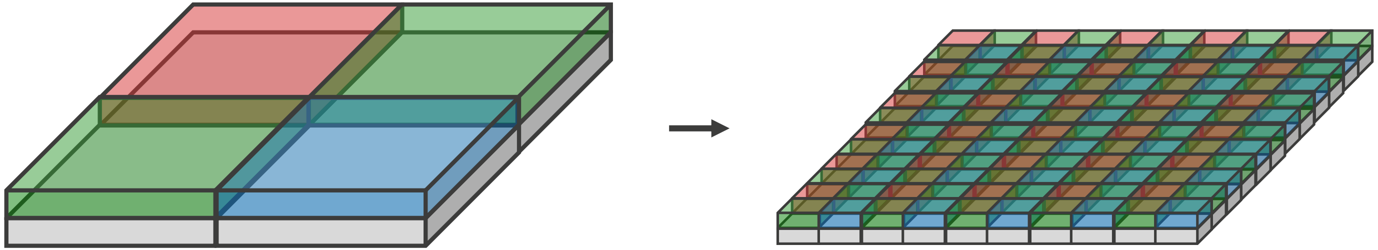


W / L = 10 µm / 3 µm

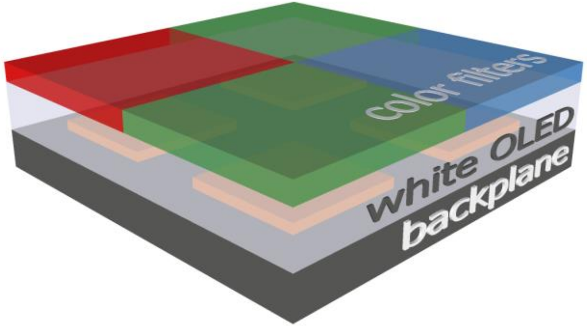


OLED FRONTPLANE

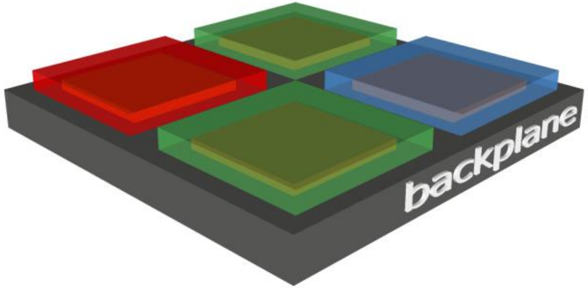
OLED FRONTPLANE SCALING



WOLED VS. RGB OLED

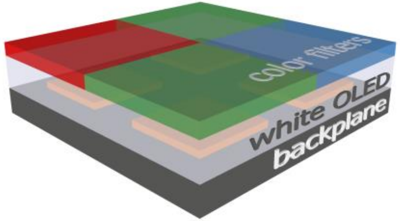


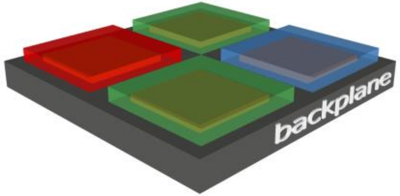
WOLED color-by-white



RGB OLED side-by-side

WOLED VS. RGB OLED



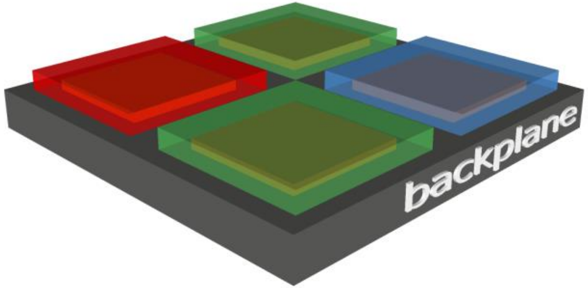


	WOLED color-by-white		**RGB OLED** side-by-side	
pixel density	✓	limited by backplane (CMOS <1 μm)	✗	limited by OLED dep. (FMM < 800 ppi)
aperture ratio	✓	high	✗	low
brightness	✗	limited by color filters	✓	optimum for each color
power	✗	high	✓	low
typical usage		▣ 🖥		⌚ 📱

WOLED VS. RGB OLED

FABRICATION METHODS

- FMM – Fine Metal Masking
  - difficult above 600-800 ppi
- IJP – Inkjet Printing
  - soluble materials needed
- photolithography
  - challenging chemically



RGB OLED side-by-side

RGB OLED BY PHOTOLITHOGRAPHY

DISRUPTIVE TECHNOLOGY

OPPORTUNITY:

high pixel density / high aperture ratio / multicolor / large substrate size

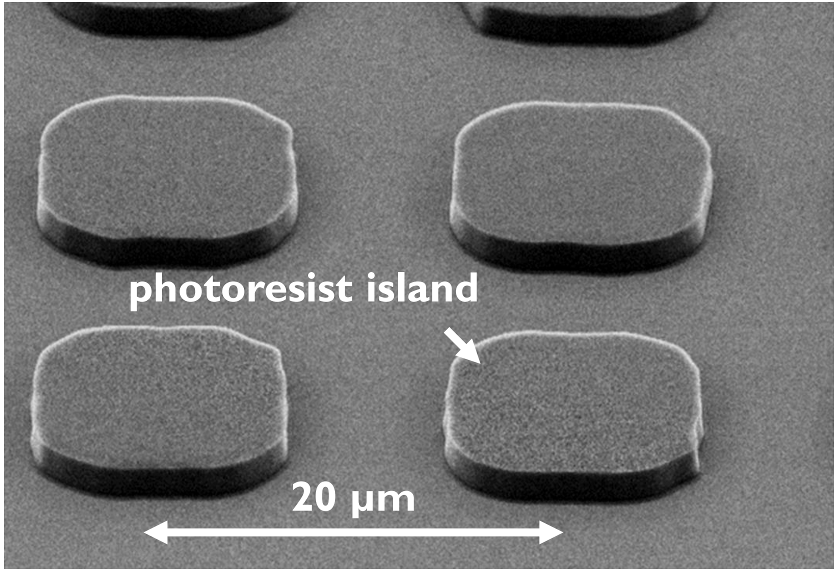
CHALLENGE:

photolithography compatible with OLEDs

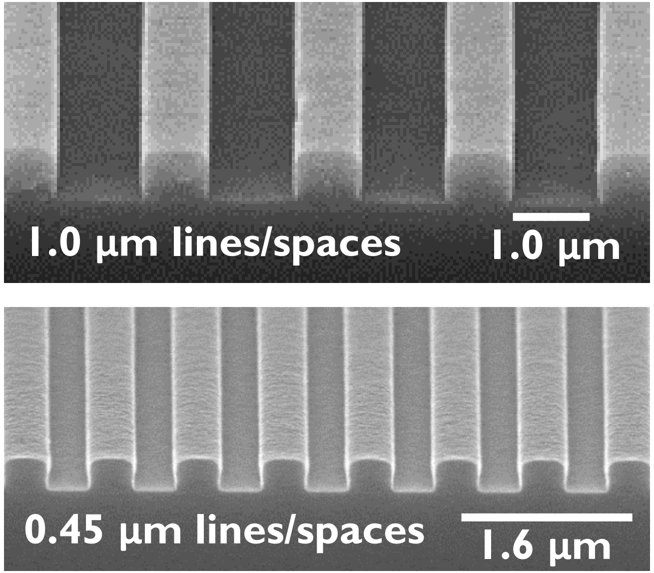
imec ↔ FUJIFILM

PHOTORESIST RESOLUTION

0.45 MICRON LINES/SPACES FEASIBLE



contact aligner exposure

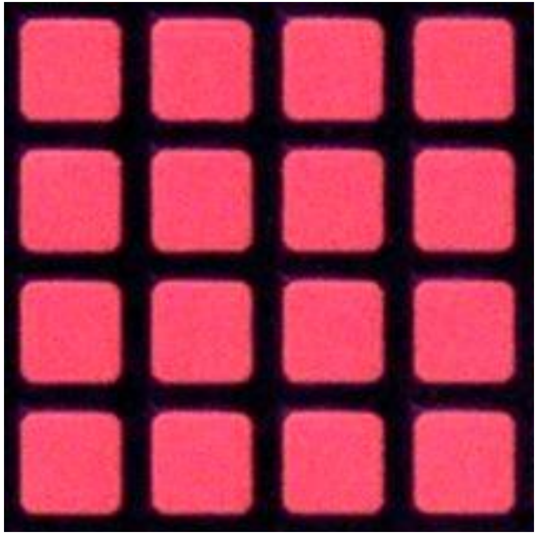


i-line stepper

HIGH APERTURE RATIO

BETTER USAGE OF THE ACTIVE AREA

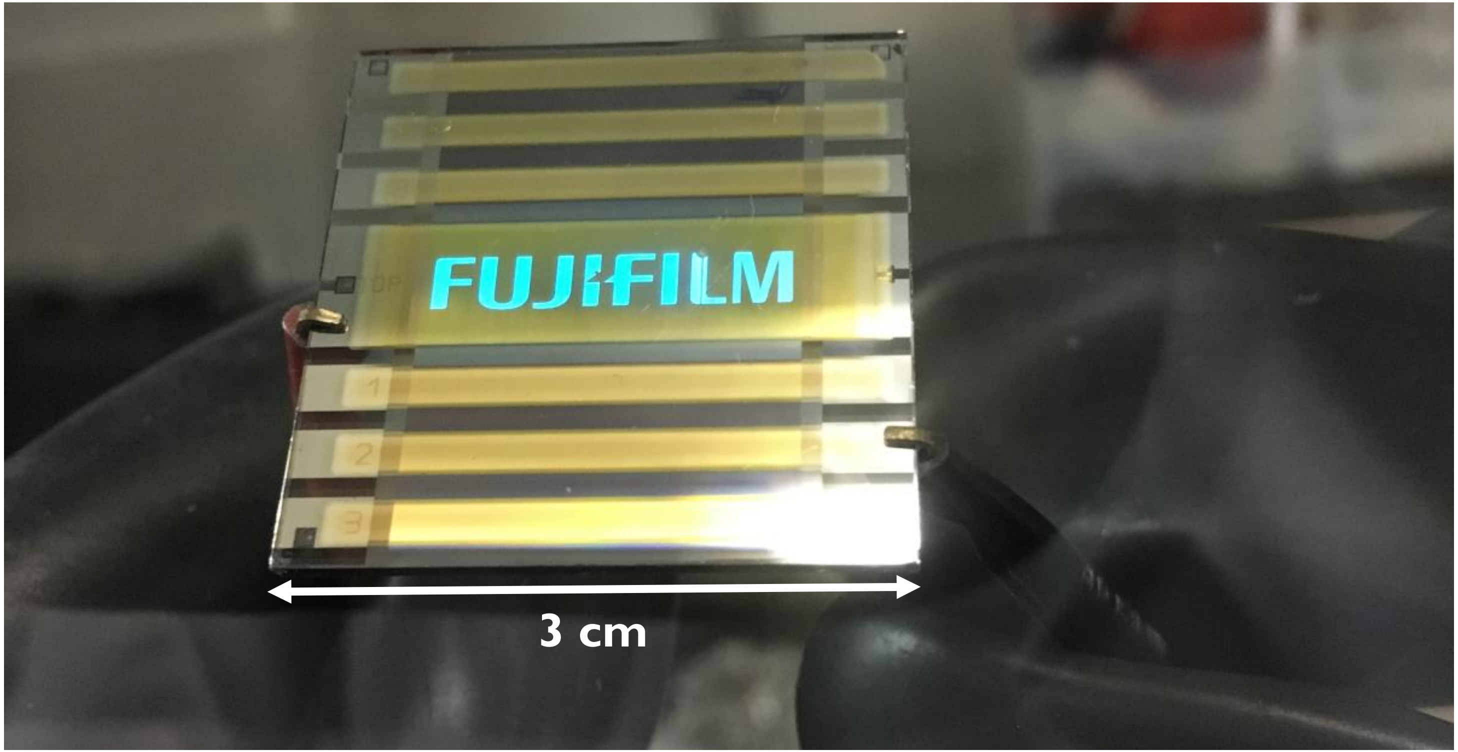
- targets:
  - minimum pixel spacing – below 1 µm
  - maximum emitting area
- higher aperture ratio yields longer lifetime



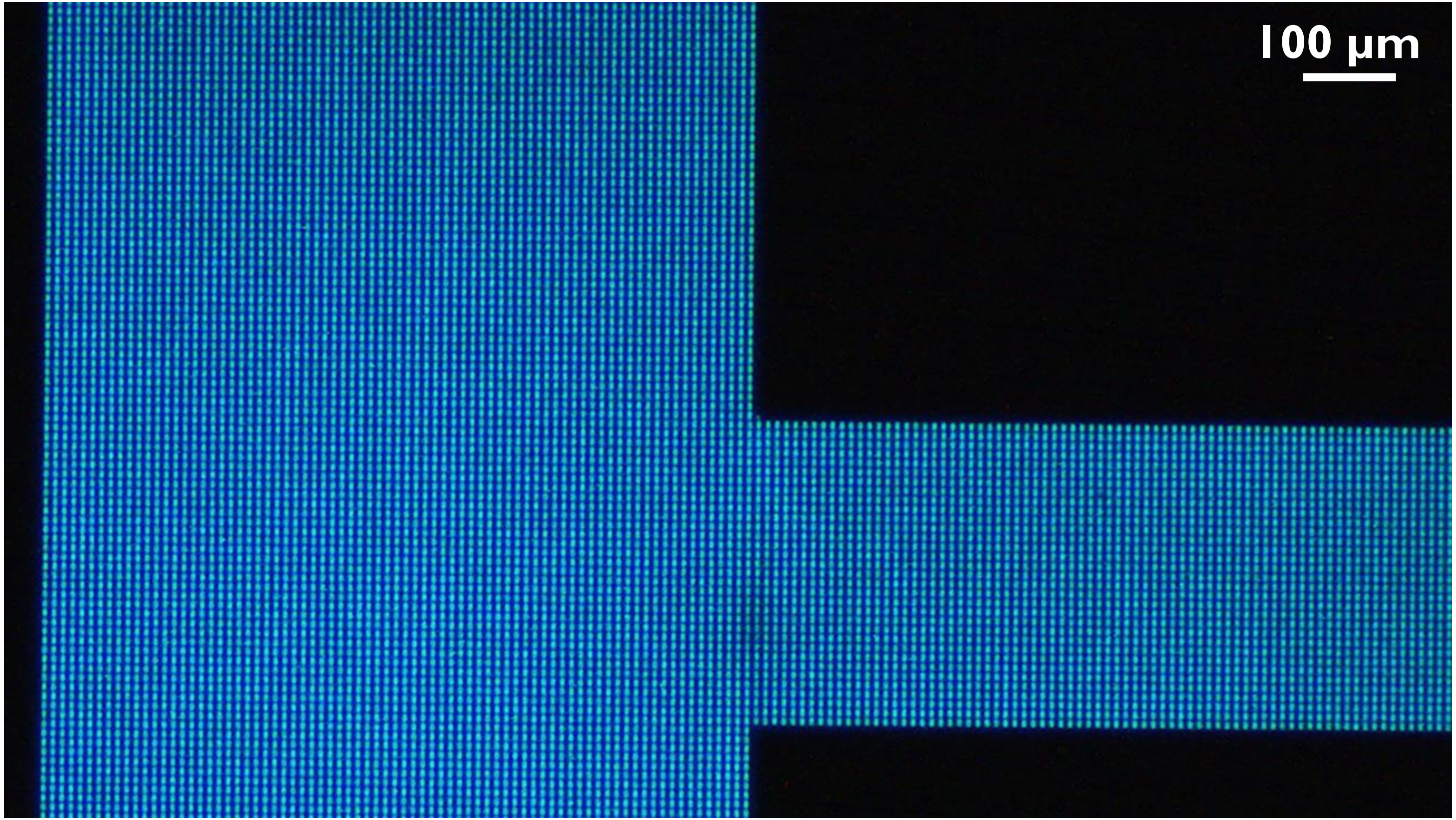
photoluminescence

2500 PPI PASSIVE DISPLAY: FLUORESCENT BLUE

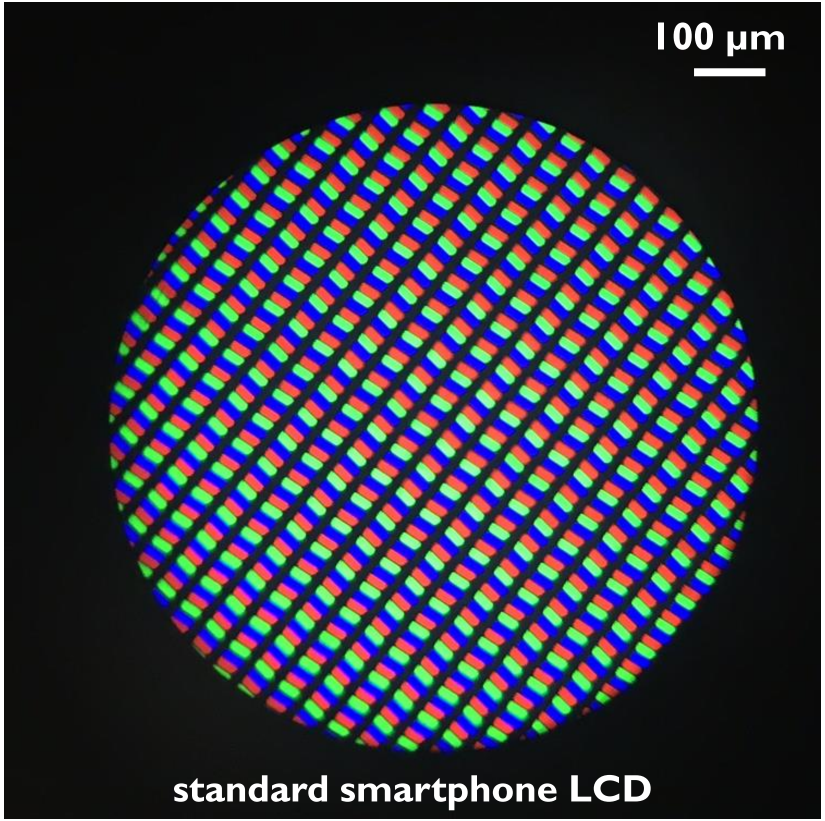
1900x600 PIXELS, PASSIVE DISPLAY, TOP EMISSION



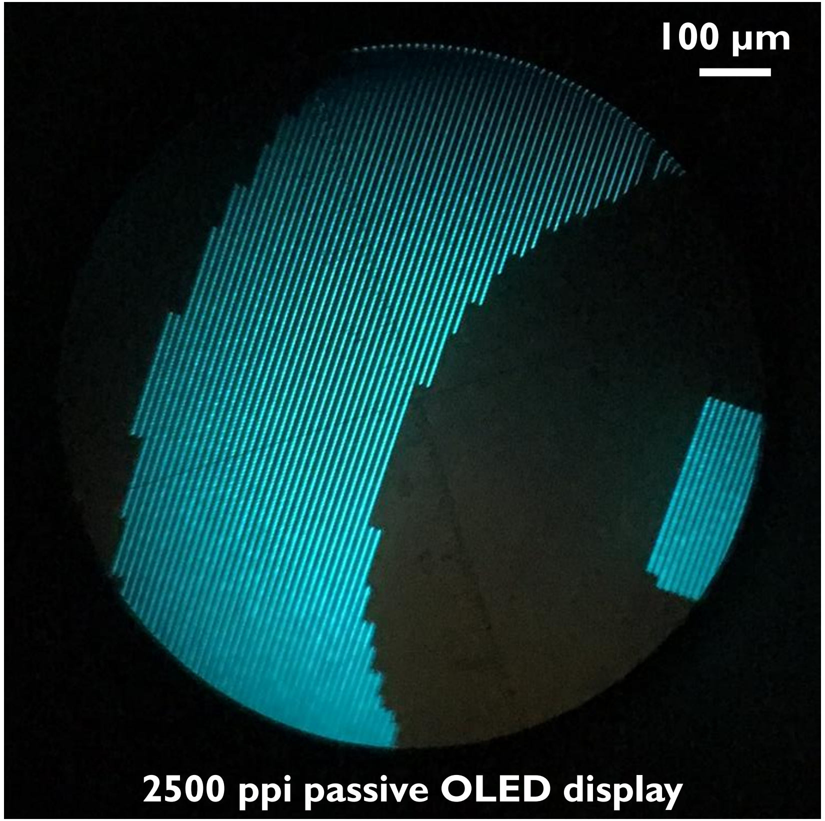
2500 PPI PASSIVE DISPLAY: FLUORESCENT BLUE



PASSIVE OLED DISPLAY DEMO



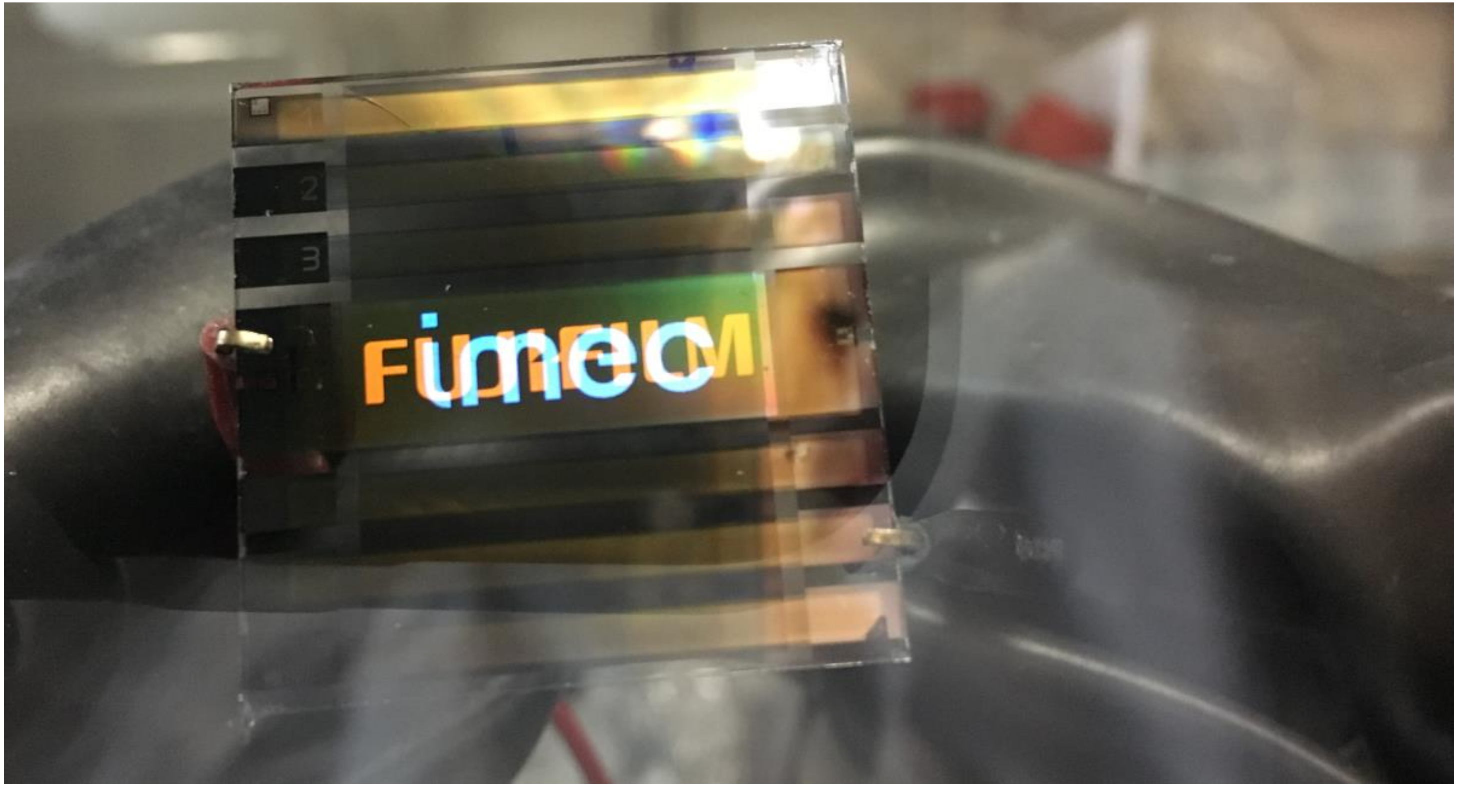
standard smartphone LCD



2500 ppi passive OLED display

1250 PPI DOUBLE COLOR – ORANGE/BLUE

1900x600 SUBPIXELS, PASSIVE DISPLAY, TOP EMISSION



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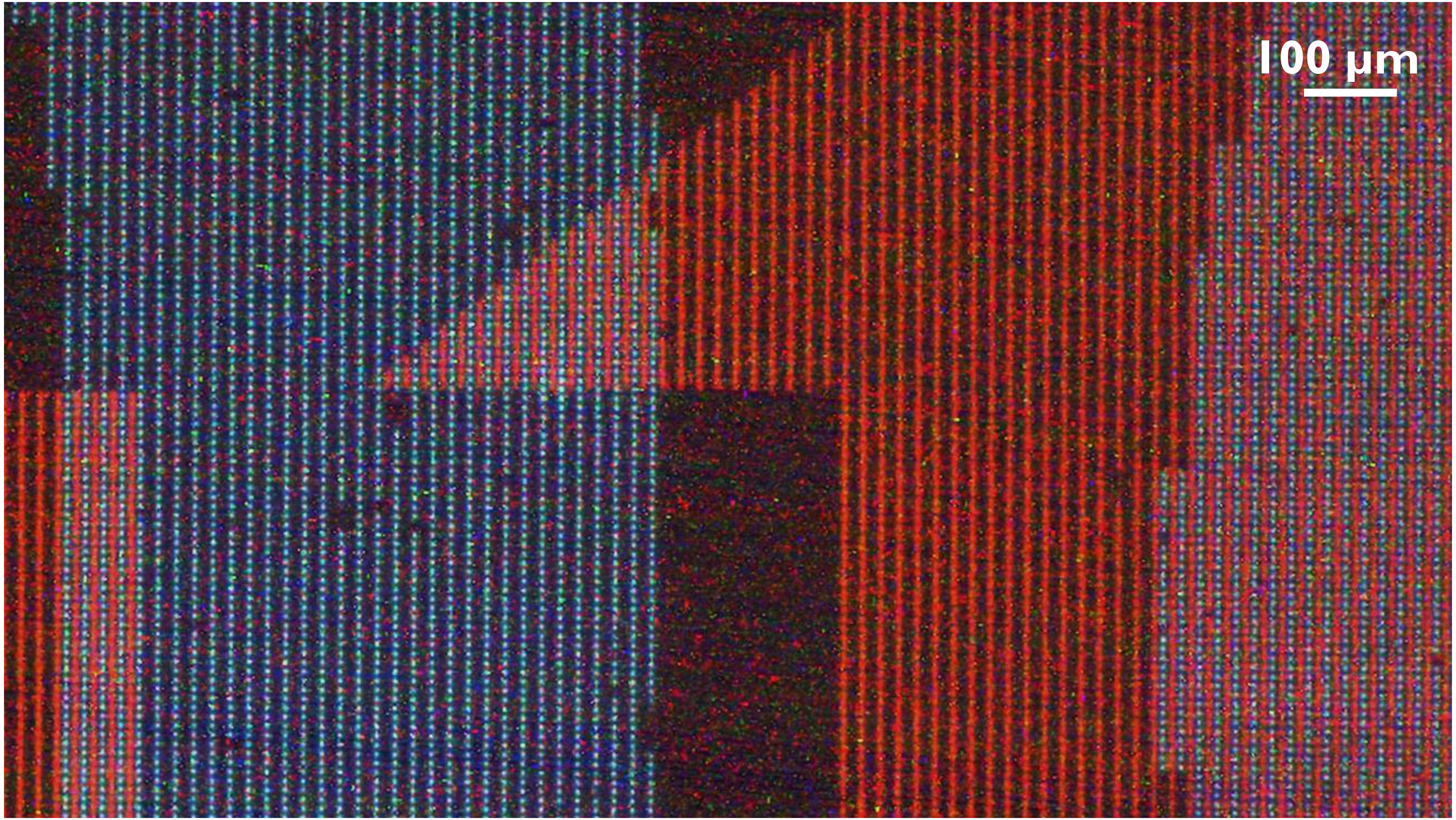
1250 PPI DOUBLE COLOR – ORANGE/BLUE



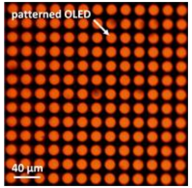
HIGH RESOLUTION OLED PATTERNING PROGRESS

TACKLING 2 MAIN CHALLENGES: **RESOLUTION** AND LIFETIME

Resolution progress

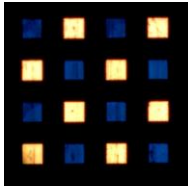
status today

low-res (125 ppi)
single color



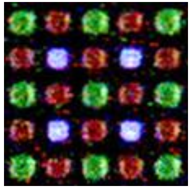
press release

low-res (125 ppi)
double color



ITE SID
IDW '14
THE 21ST INTERNATIONAL
DISPLAY WORKSHOPS

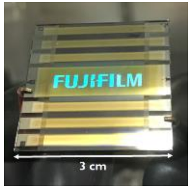
high-res (640 ppi)
RGB



press release

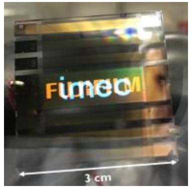
DISPLAY WEEK 2015
SID SAN JOSE

UHD (2500 ppi)
single color



DISPLAY WEEK
SAN FRANCISCO 2016

UHD (1250 ppi)
RGB



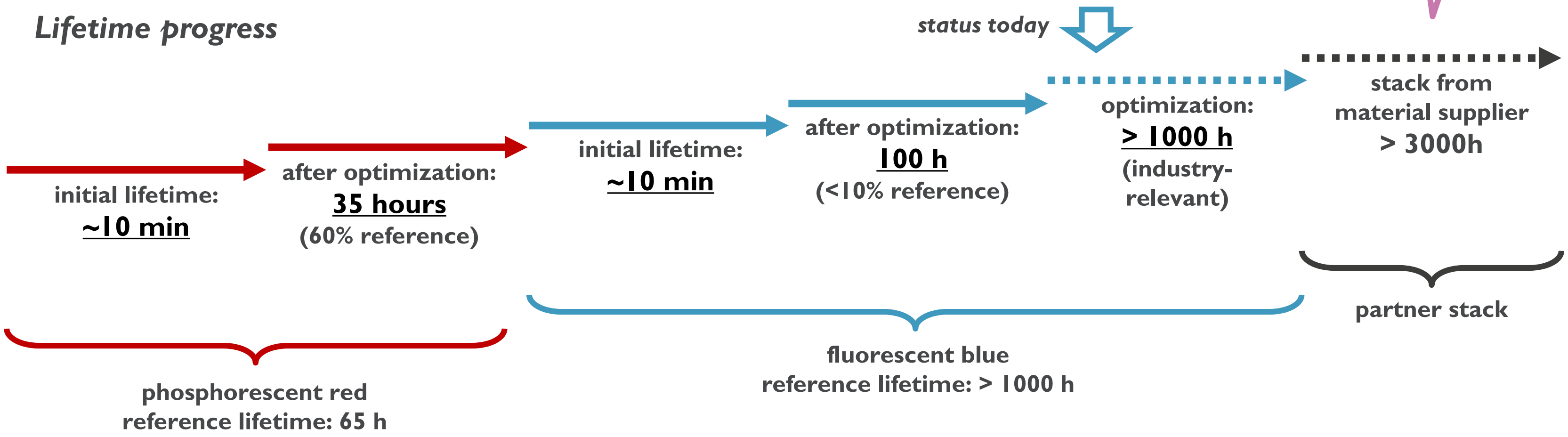
VR (>1250 ppi)
RGB

HIGH RESOLUTION OLED PATTERNING PROGRESS

TACKLING 2 MAIN CHALLENGES: RESOLUTION AND **LIFETIME**

IDW/AD '16

ITE SID



Lifetime progress

status today

initial lifetime:
~10 min

after optimization:
35 hours
(60% reference)

initial lifetime:
~10 min

after optimization:
100 h
(<10% reference)

optimization:
> 1000 h
(industry-relevant)

stack from
material supplier
> 3000h

phosphorescent red
reference lifetime: 65 h

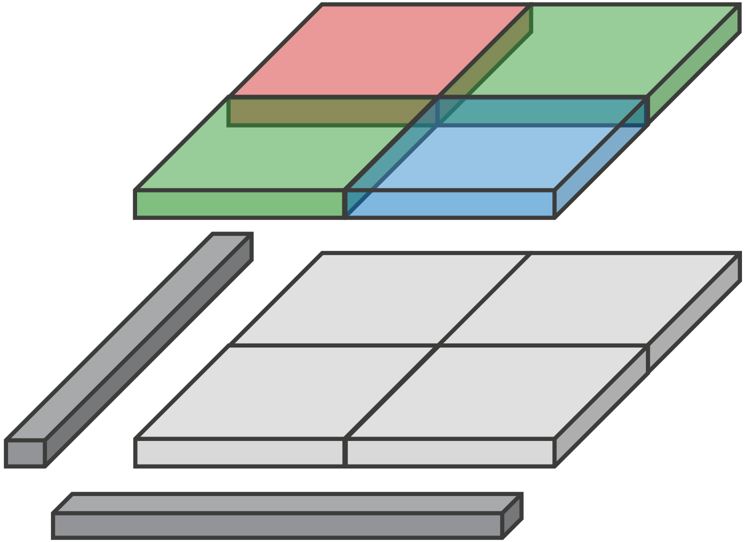
fluorescent blue
reference lifetime: > 1000 h

partner stack

SUMMARY

TOWARDS HIGHER PIXEL DENSITY

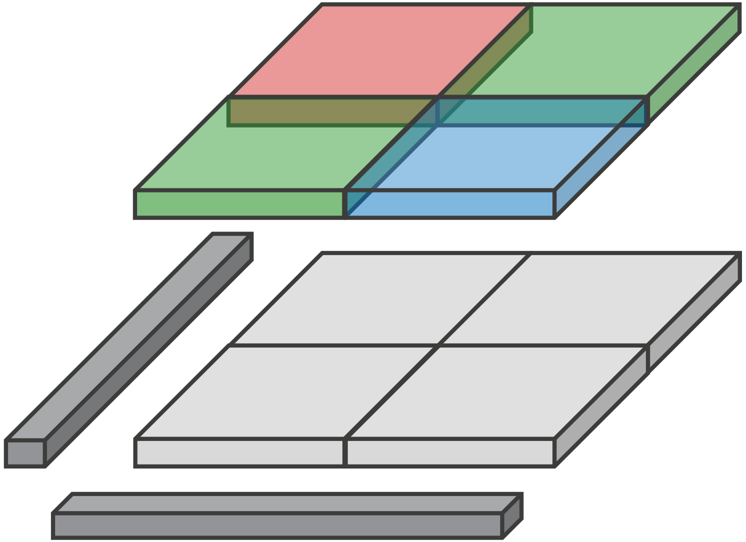
IMPROVEMENTS IN 3 AREAS:



FRONTPLANE	RGB resolution higher aperture ratio
BACKPLANE	better semiconductors compact architectures process resolution
DRIVING	integrated drivers PWM scheme

TOWARDS HIGHER PIXEL DENSITY

IMPROVEMENTS IN 3 AREAS:



RGB resolution
higher aperture ratio

OLED patterning by litho

better semiconductors
compact architectures
process resolution

spatial ALD IZO
2T1C, self-aligned TFT

integrated drivers
PWM scheme

integrated gate driver
digital current driving

imec magazine

NOVEMBER 2016

VIDEO
In pursuit of intelligent swarms of robots

FROM THE LABS
Chips must learn how to feel pain

OPINION
Getting all aboard the digital bandwagon!

BUSINESS
Imec builds springboard for tech entrepreneurs

> "I truly believe wearables will be a normal part of our daily lives within 10 years."
>
> Chris Van Hoof, Program Director Wearable Healthcare

고맙습니다

SMALL PITCH, HIGH RESOLUTION – SCALING OF OLED DISPLAYS

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embracing a better life

IMEC / HOLST FLEXIBLE AMOLED TRACK RECORD

- S. Steudel et al. "Flexible AMOLED Display with Integrated Gate Driver Operating at Operation Speed Compatible with 4k2k", 29.4, SID Display Week 2015
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