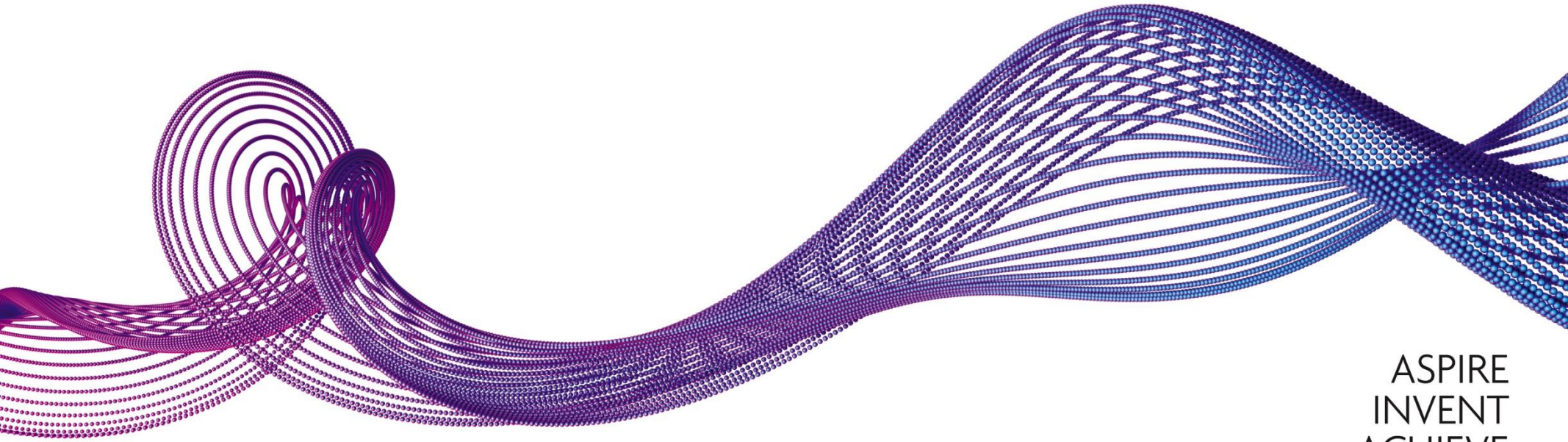
LARGE AREA ELECTRONICS
MAGICAL PLASTIC FOILS

PAWEL MALINOWSKI



ASPIRE
INVENT
ACHIEVE

Introduction

Internet of Things

IMEC

Large Area Electronics

Circuits

Displays

Image Sensors

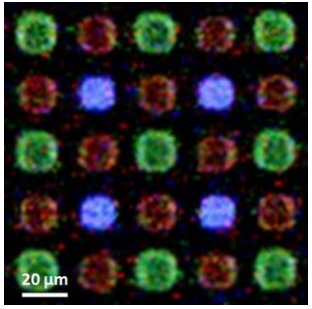
Workshop

PAWEŁ MALINOWSKI

SINCE 2011: SENIOR RESEARCHER AT IMEC:

THIN-FILM ELECTRONICS GROUP

OPD/TFPD, HI-RES OLED, INTEGRATION



INTRODUCTION

INTERNET OF THINGS

IMEC

LARGE AREA ELECTRONICS

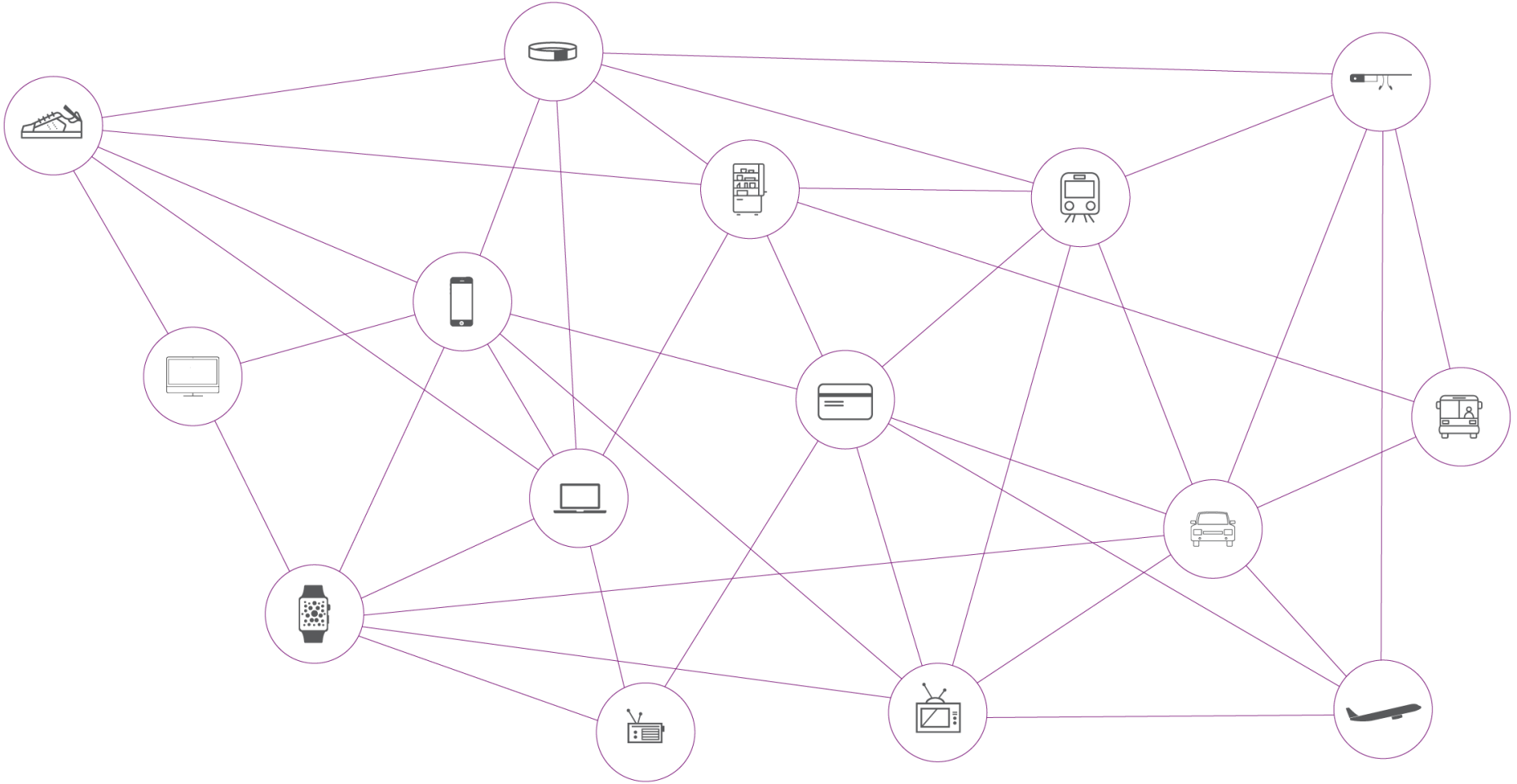
CIRCUITS

DISPLAYS

IMAGE SENSORS

WORKSHOP

INTERNET OF THINGS



Connected Devices

MOBILE WORLD LIVE | LATEST | APPS | ASIA | DEVICES | M

HOME

Number of devices to hit 4.3 per person by 2020 – report

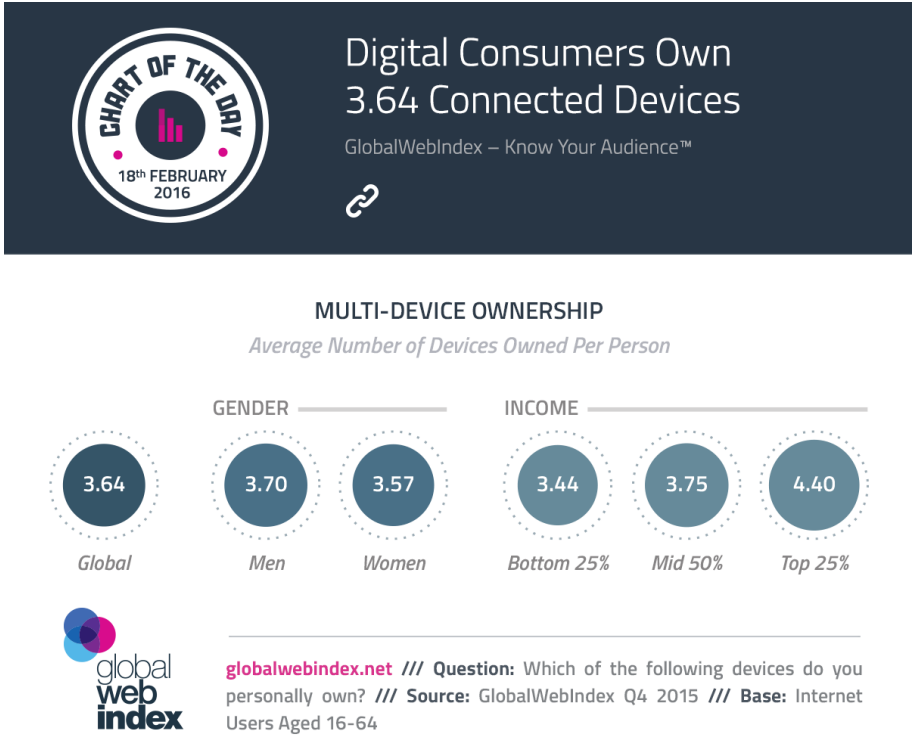
16 OCT 2014

BUSINESS INSIDER | ENTERPRISE

By 2017, We'll Each Have 5 Internet Devices

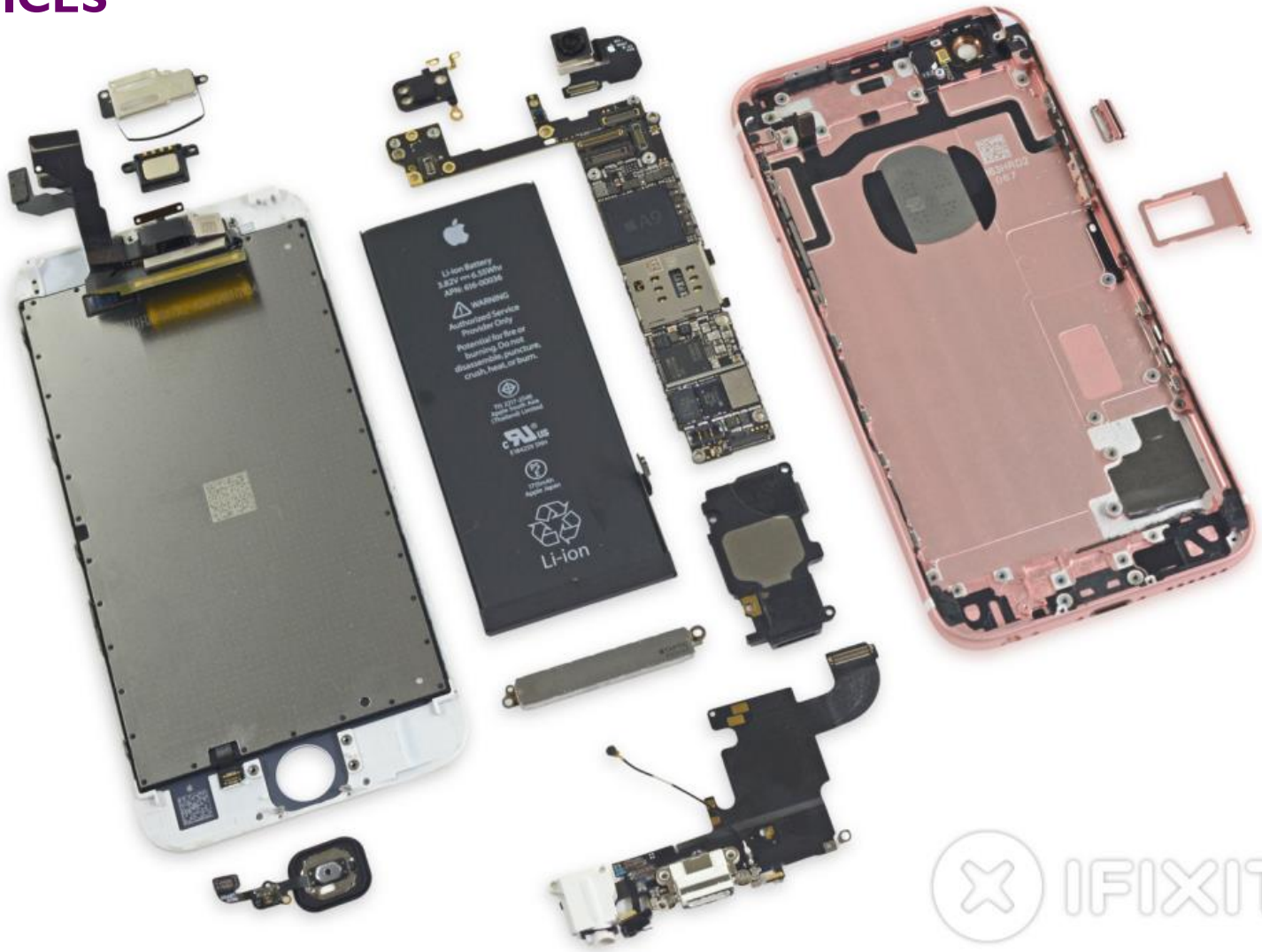
Julie Bort

May 29, 2013, 9:00 PM 120,415 8

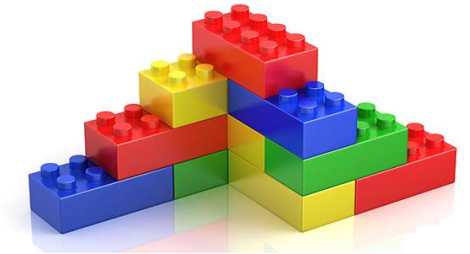


CONNECTED DEVICES

APPLE IPHONE 6S



WHAT ARE THE TECHNOLOGY BLOCKS?



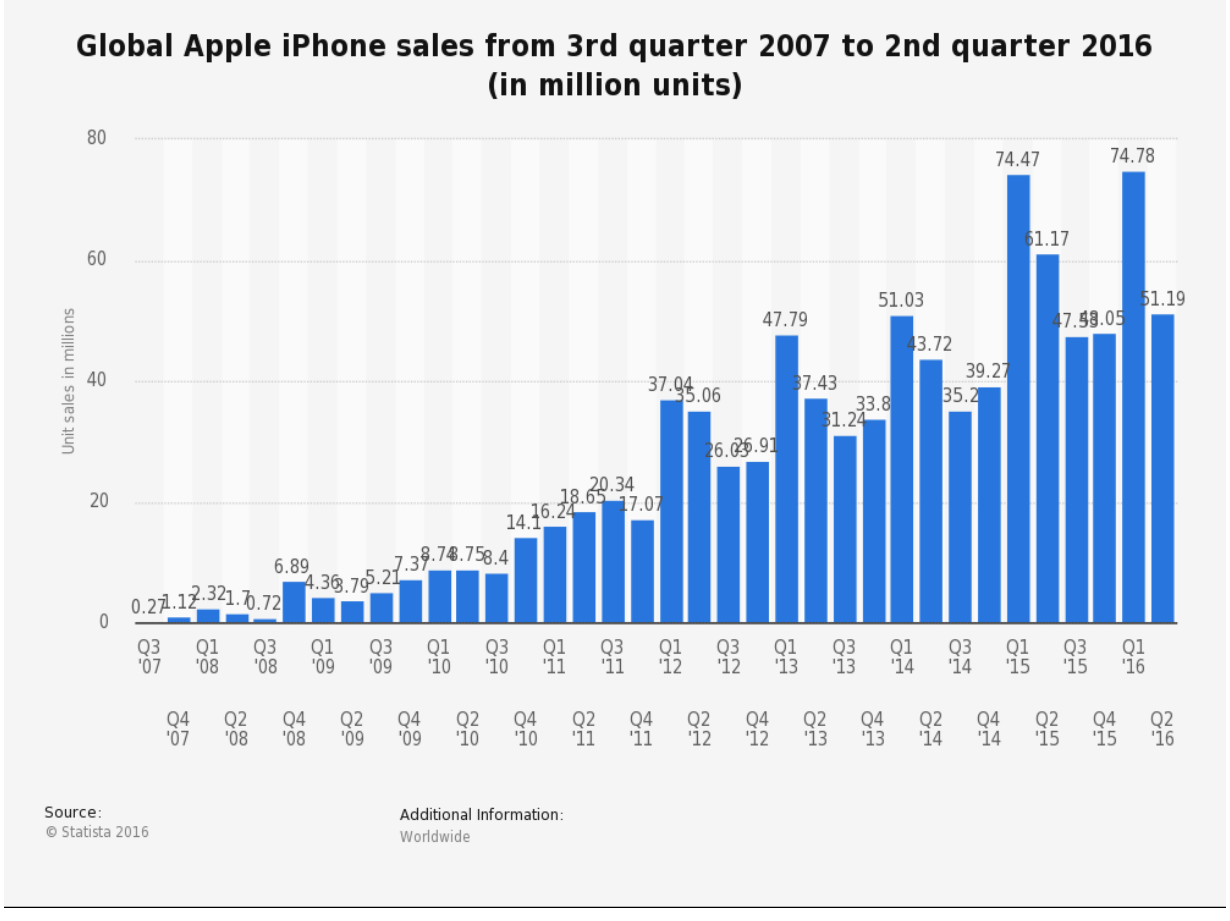
CONNECTED DEVICES

APPLE IPHONE 6S

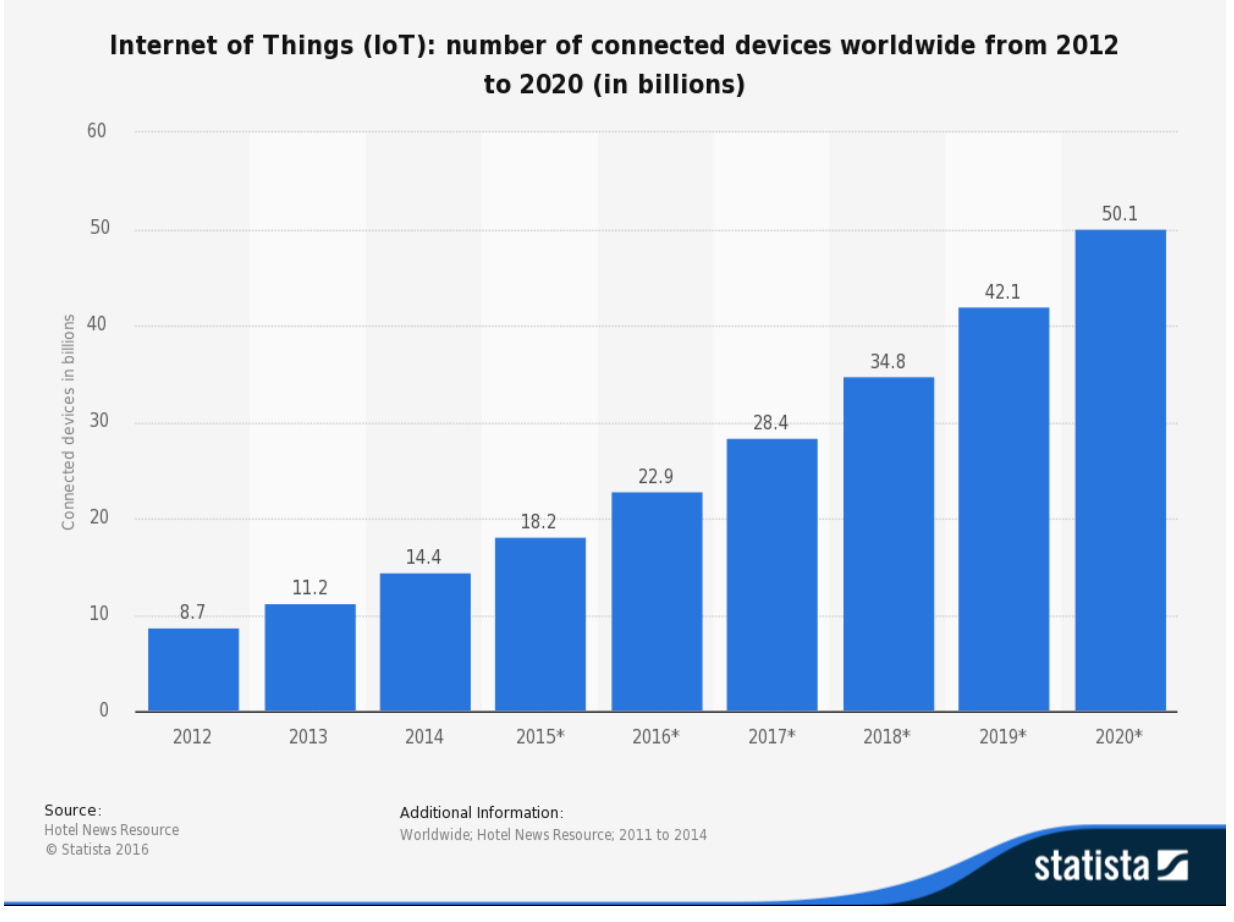
Notes:
* Costs are based off of TechInsights Quick Turn estimates. The costs are likely to be different once full teardown analysis is performed.
** NAND normalized to 16 GB units

CONNECTED DEVICES

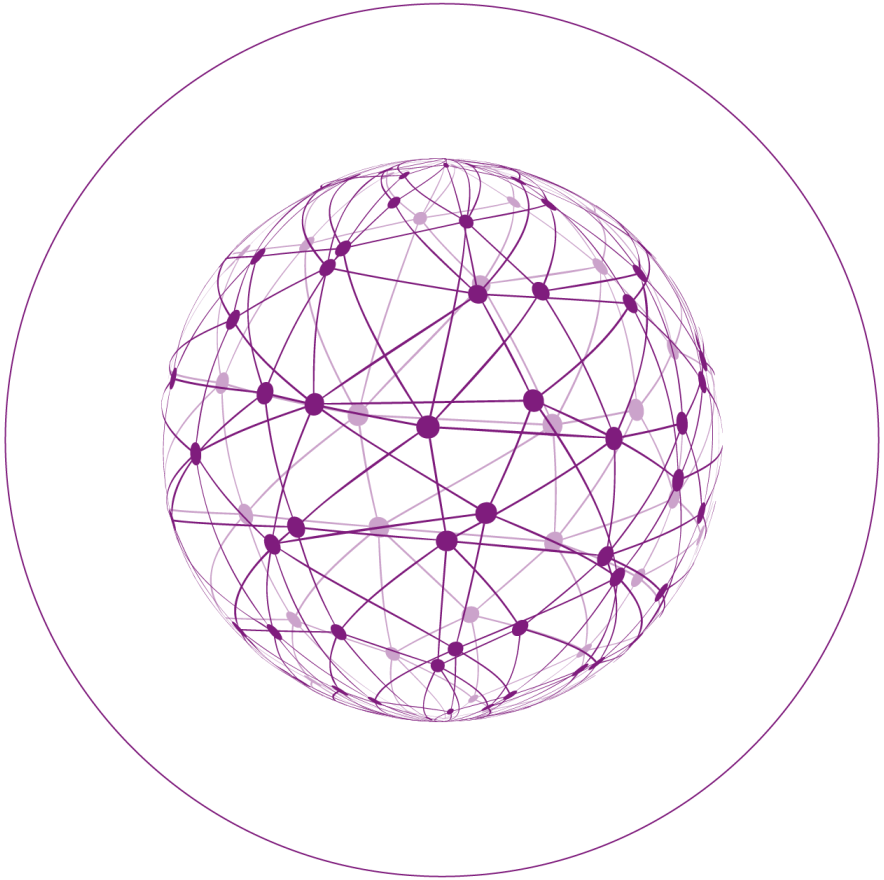
APPLE IPHONE 6S

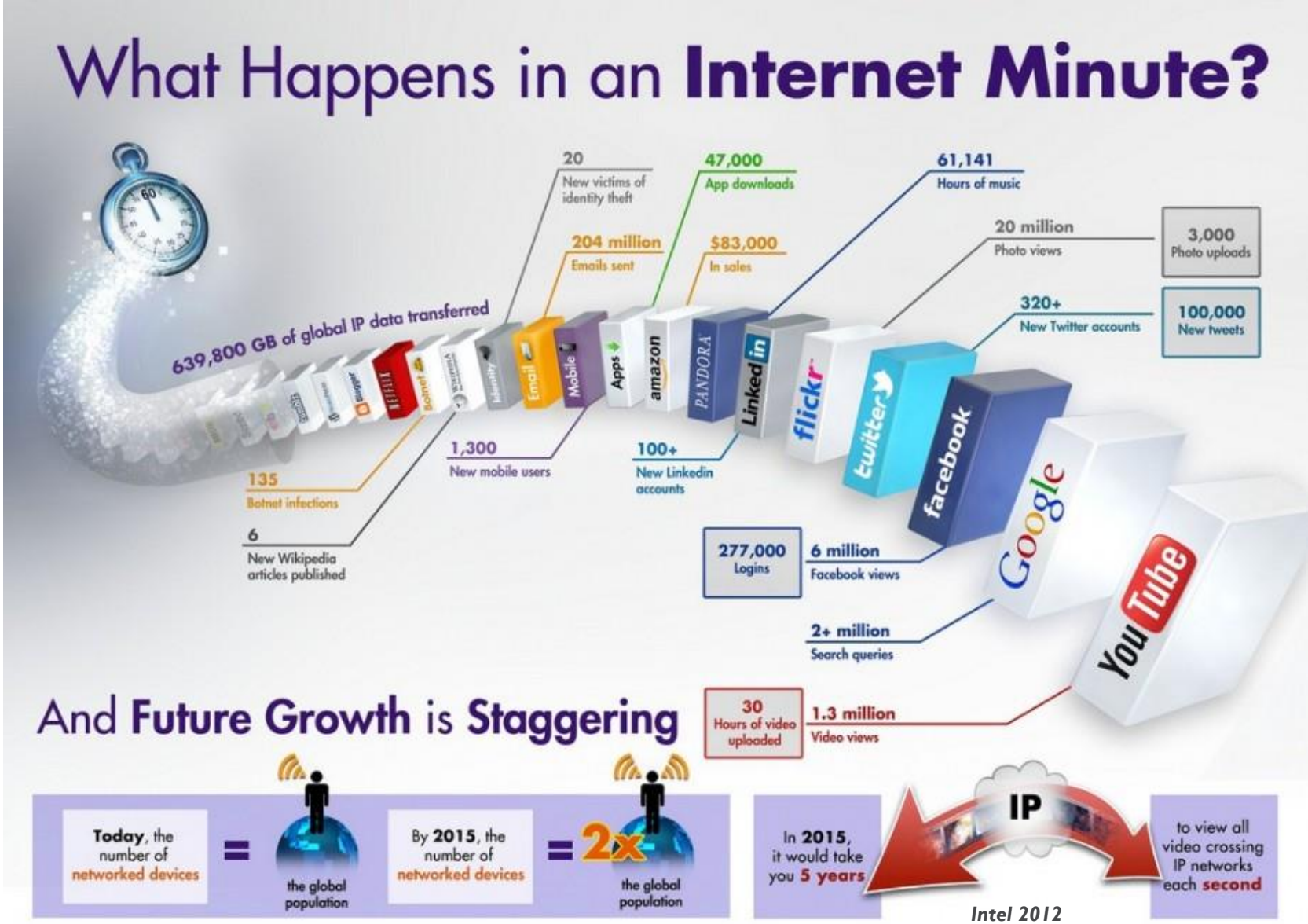


>20 Billions Connected Devices



50 BILLION CONNECTED DEVICES BY 2020




What Happens in an Internet Minute?
639,800 GB of global IP data transferred
20
New victims of identity theft
47,000
App downloads
61,141
Hours of music
204 million
Emails sent
$83,000
In sales
20 million
Photo views
3,000
Photo uploads
320+
New Twitter accounts
100,000
New tweets
135
Botnet infections
1,300
New mobile users
100+
New Linkedin accounts
6
New Wikipedia articles published
277,000
Logins
6 million
Facebook views
2+ million
Search queries
30
Hours of video uploaded
1.3 million
Video views
Email
Mobile
Apps
amazon
PANDORA
LinkedIn
flickr
twitter
facebook
Google
YouTube
And Future Growth is Staggering
Today, the number of networked devices
=
the global population
By 2015, the number of networked devices
= 2x
the global population
In 2015, it would take you 5 years
IP
to view all video crossing IP networks each second

Intel 2012

80 million
cars/year

2000 million
devices/year

80,000 million
pieces/year

10,000,000 million
packages/year

$100+ billion OPPORTUNITY for item level electronics

Image: Best Home Appliance

WHICH TECHNOLOGY?

Trillions devices	Disposable	Unusual form-factors	Multifunctional

Challenges for IoT

Cost

Power

Performance

Integration

Production Feasibility

Possible Technology Modules for IoT

Circuit

Sensor

E.g. Light, Temperature, Mechanical, Chemical

Actuator

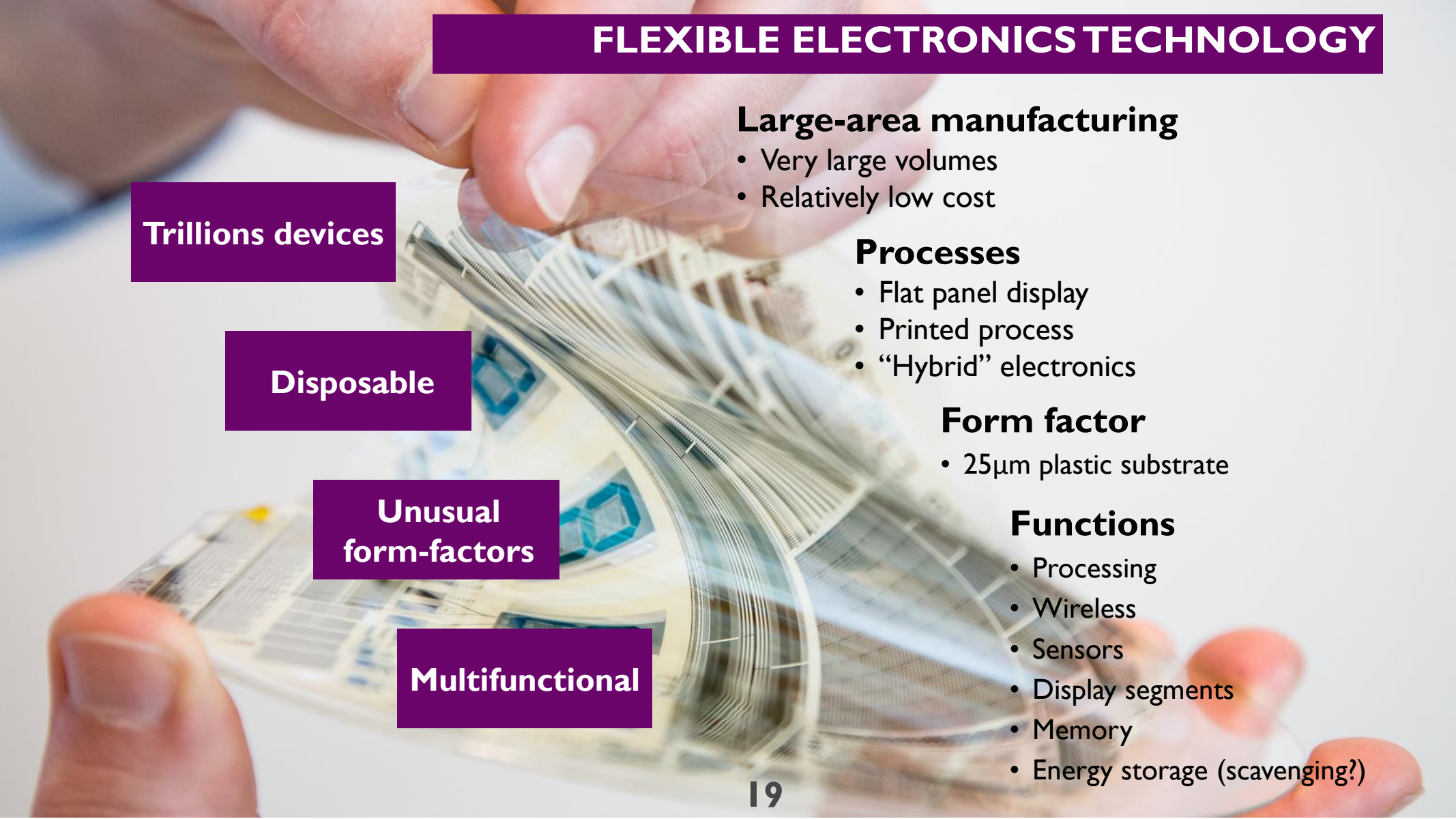
E.g. Mechanical, Ultrasound

Display

Battery

Memory

FLEXIBLE ELECTRONICS TECHNOLOGY



Trillions devices

Disposable

Unusual form-factors

Multifunctional

Large-area manufacturing

- Very large volumes
- Relatively low cost

Processes

- Flat panel display
- Printed process
- "Hybrid" electronics

Form factor

- 25μm plastic substrate

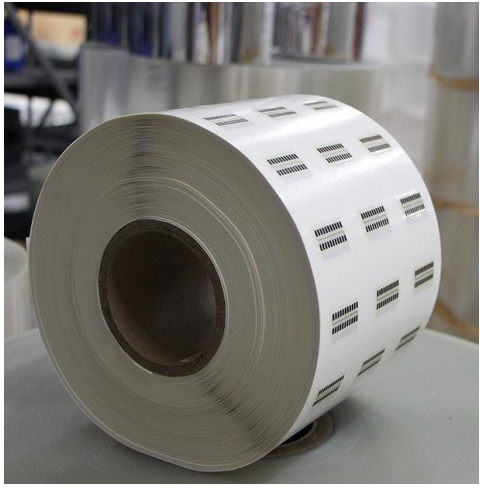
Functions

- Processing
- Wireless
- Sensors
- Display segments
- Memory
- Energy storage (scavenging?)

APPLICATION DETERMINES PERFORMANCE NEED

examples

Brand protection	Marketing	On-skin thermometer
Few bit printed FE memory	NFC tag	NFC tag plus analog electronics



ThinFilm

ThinFilm

Viva

EXAMPLE: SMART LABELS

CONTAINING: DISPOSABLE FLEXIBLE SENSOR, INDICATOR, CIRCUIT, BATTERY ...

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WORKSHOP

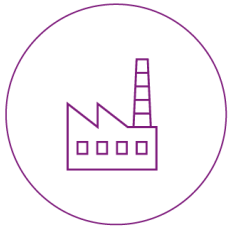
WORLD-LEADING NANOELECTRONICS RESEARCH

imec

FULL ECO SYSTEM

UNIVERSITIES

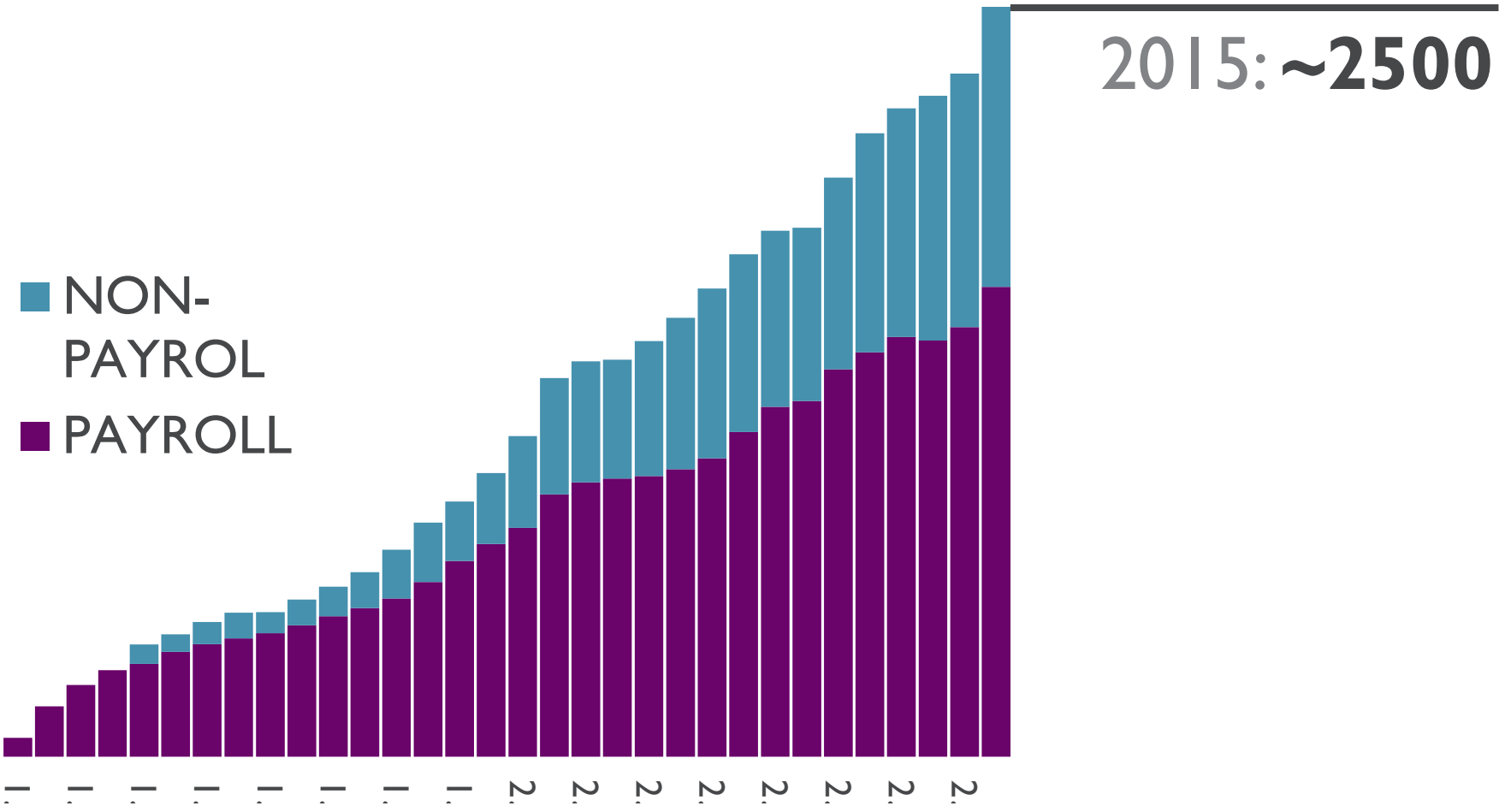
imec



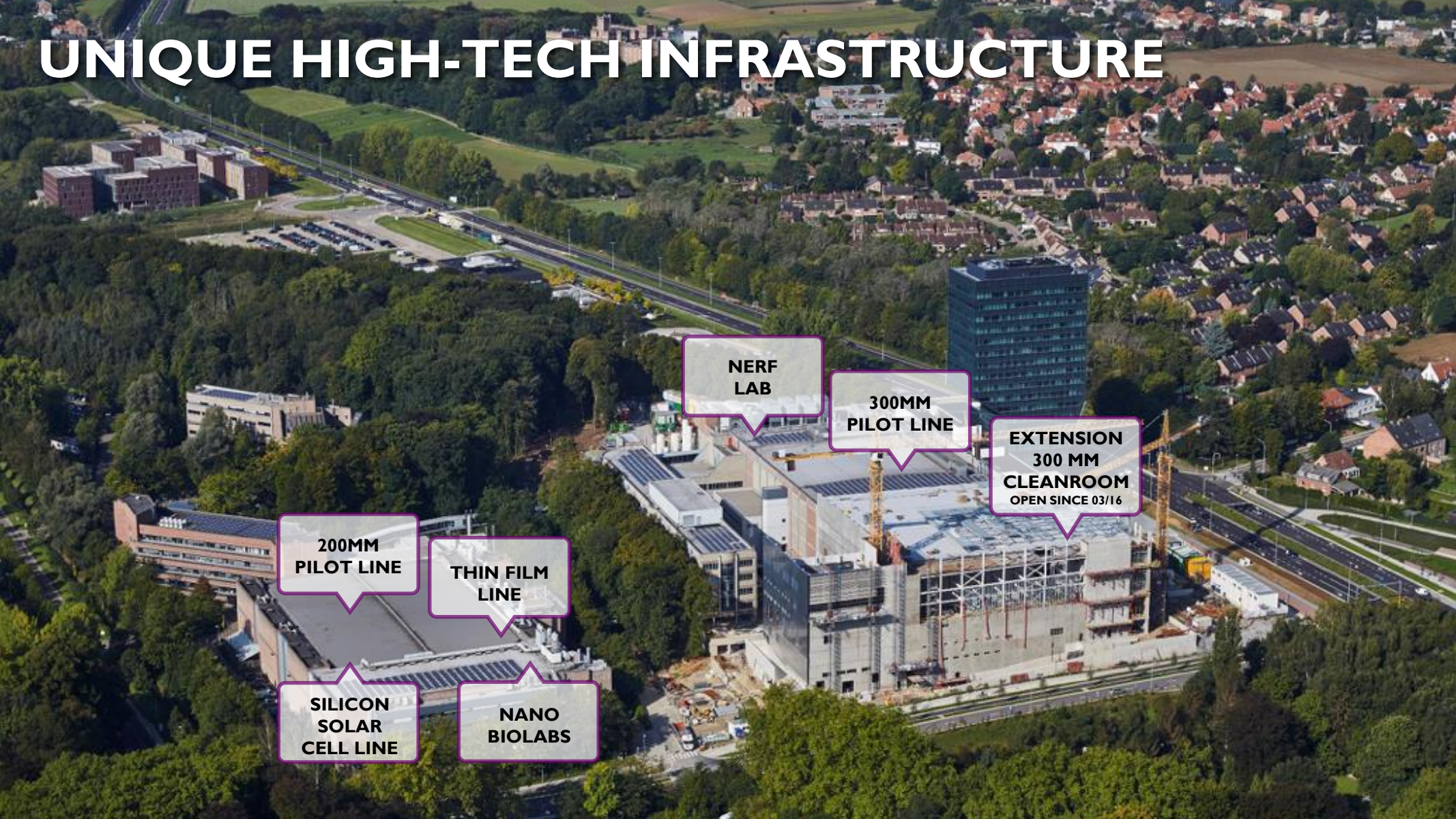
INDUSTRY

GOVERNMENT

EMPLOYEES

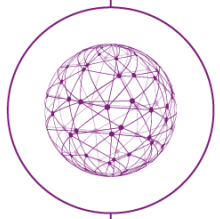


UNIQUE HIGH-TECH INFRASTRUCTURE



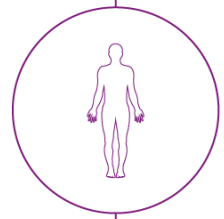
IMEC INNOVATION PLATFORM

INTUITIVE INTERNET OF THINGS



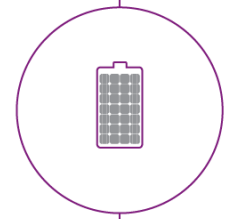
SENSING & CONNECTIVITY SOLUTIONS

INTERNET OF HEALTH



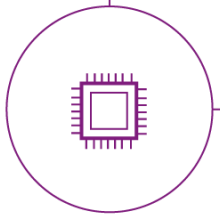
WEARABLES, DIAGNOSTICS, LIFE SCIENCES

INTERNET OF POWER



PHOTOVOLTAICS, POWER DEVICES, ENERGY STORAGE

CORE CMOS

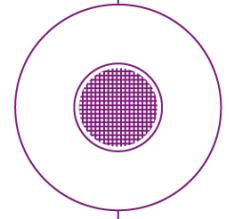


LITHOGRAPHY

DEVICES

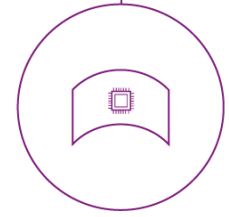
INTERCONNECTS

HETEROGENEOUS INTEGRATION



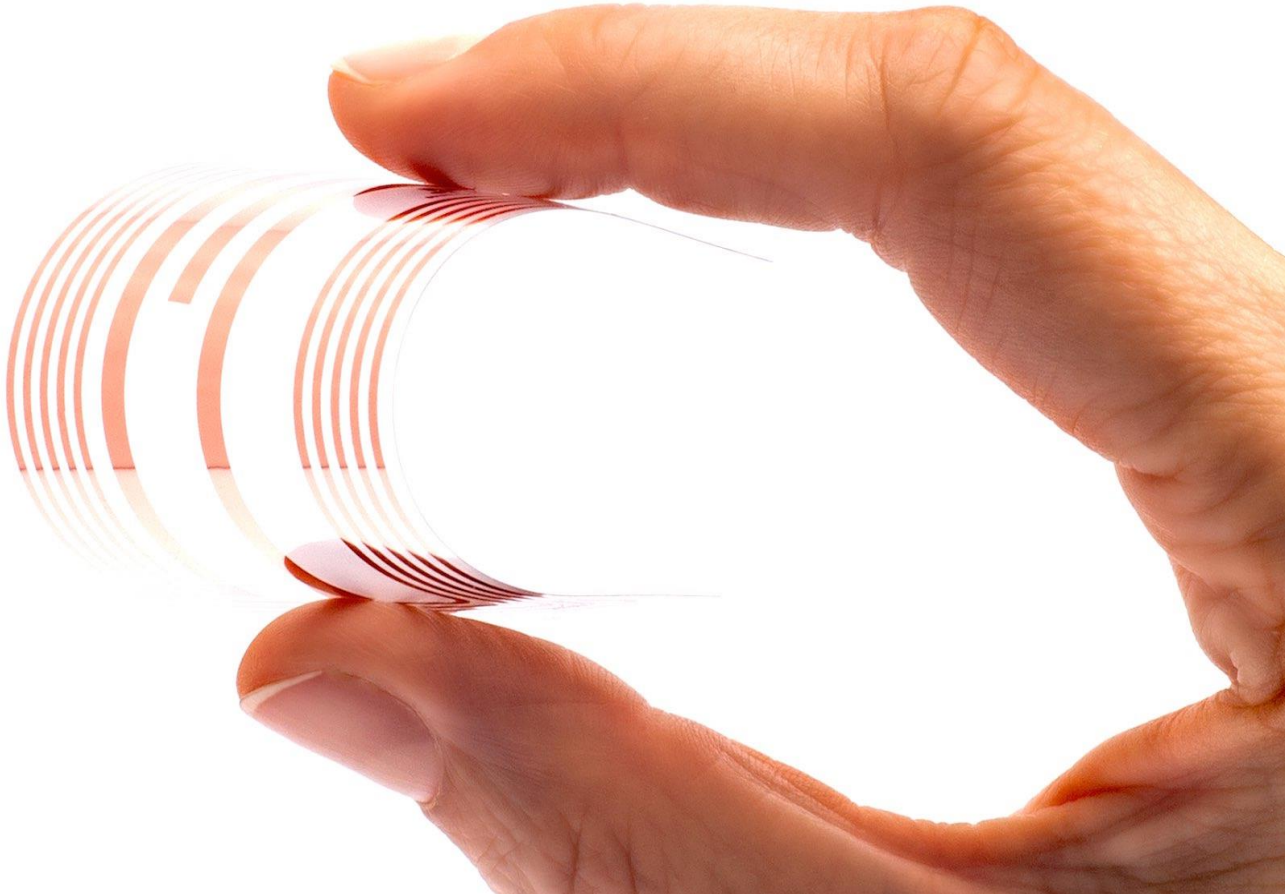
MEMS, SENSORS, PHOTONICS

FLEXIBLE ELECTRONICS



THIN-FILM ELECTRONICS

RFIDS - NFC TAGS - MEMORIES - ANTENNAS - DISPLAYS - SENSORS



imec

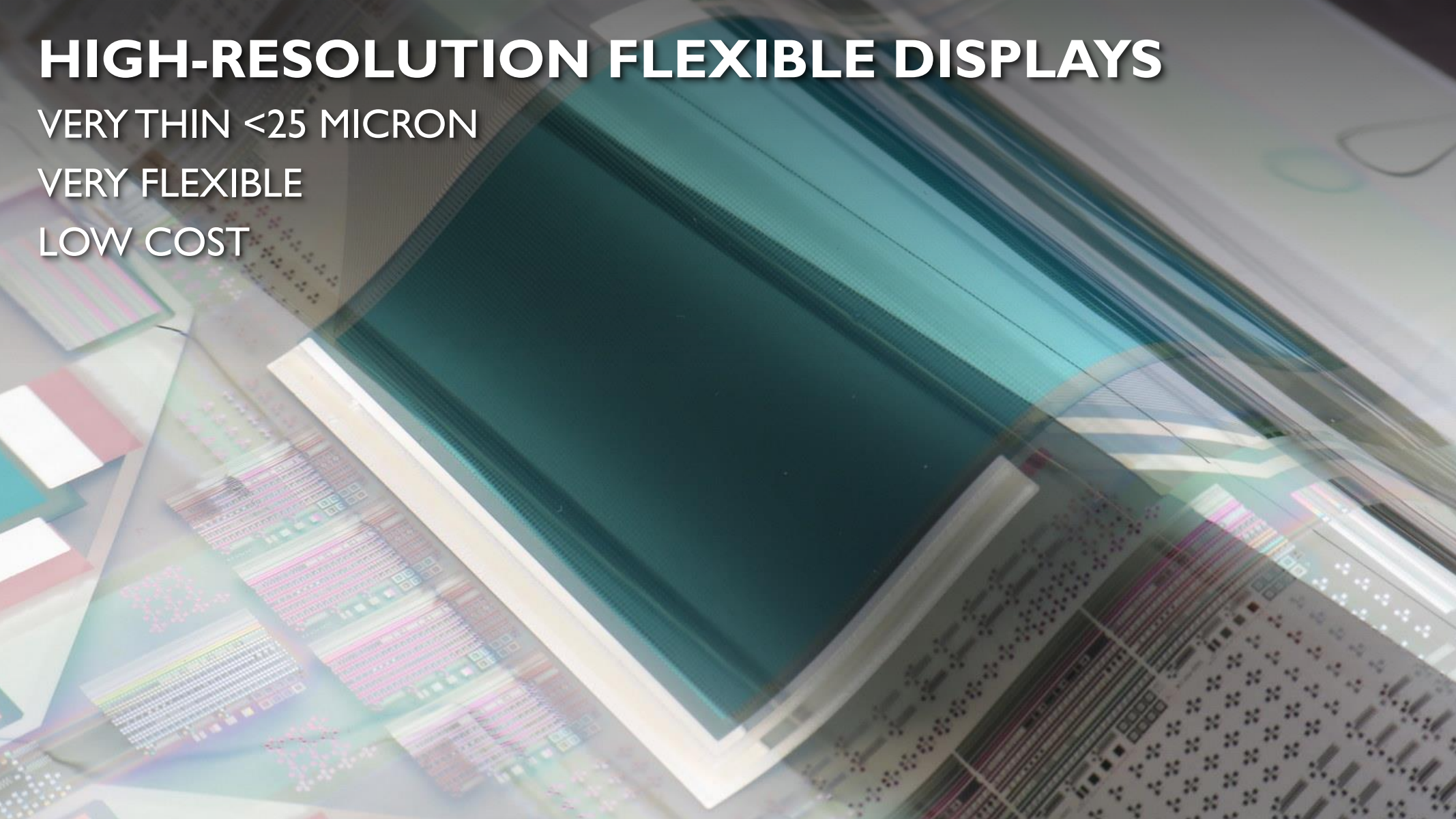
SMART RFID TAGS

BRAND AUTHENTICITY

ADVICE

SMART RFID TAGS

AUTHENTICITY - CORRECT USE

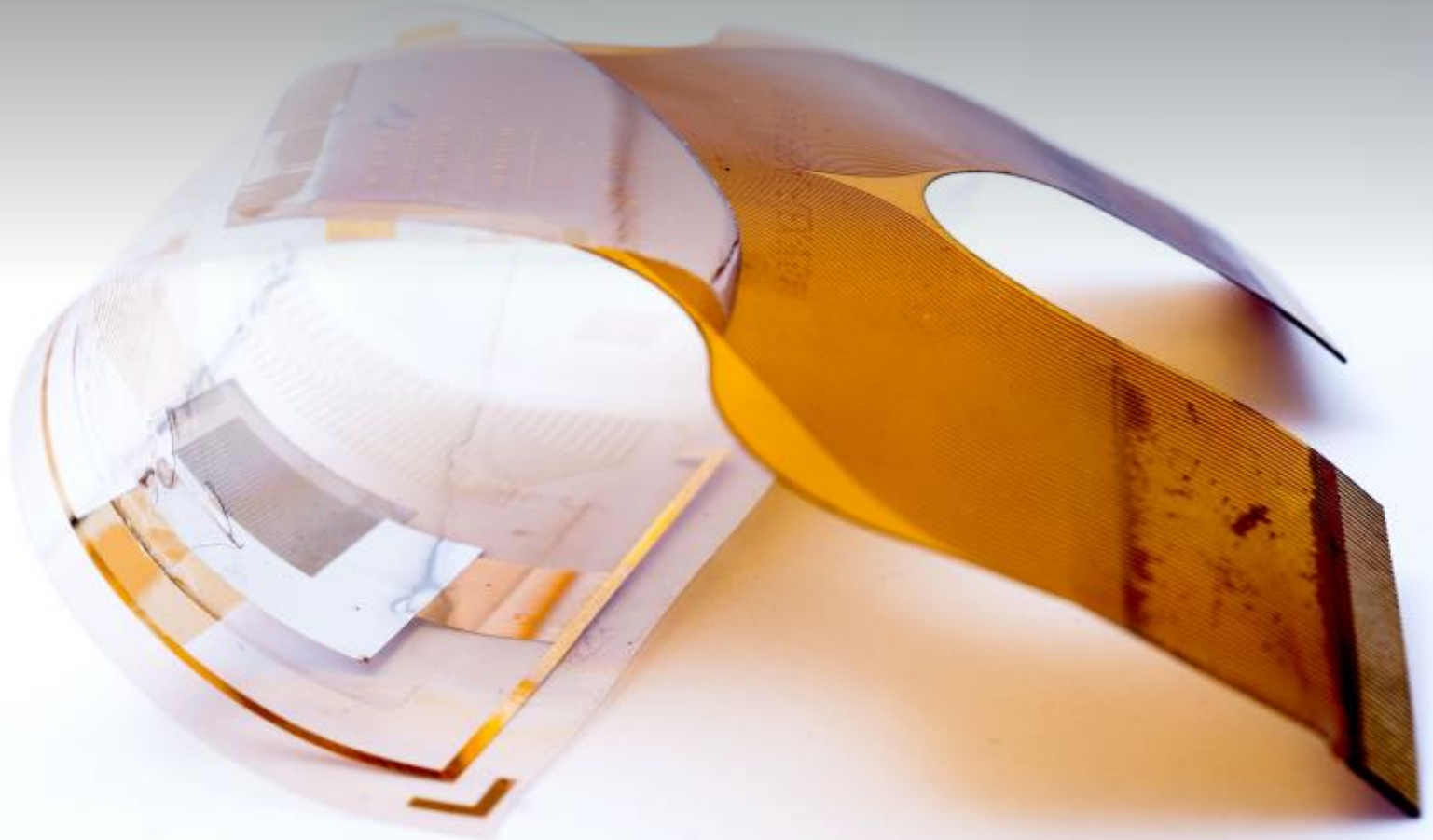

HIGH-RESOLUTION FLEXIBLE DISPLAYS
VERY THIN <25 MICRON
VERY FLEXIBLE
LOW COST

LARGE AREA, FLEXIBLE IMAGERS

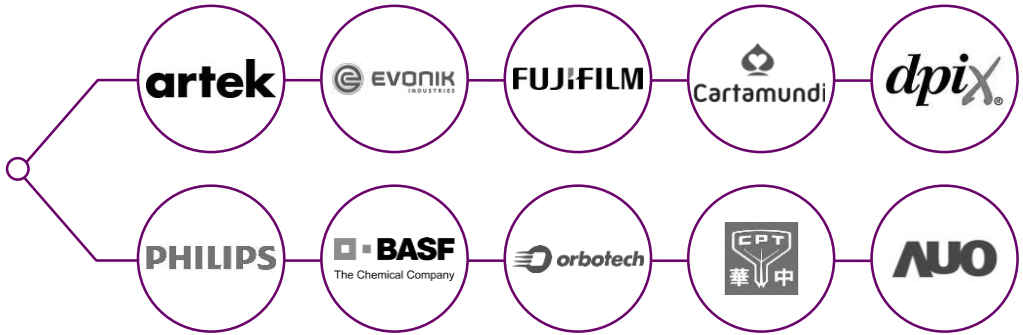
VERY THIN <25 MICRON

VERY FLEXIBLE

LOW COST



PARTNERS FLEXIBLE ELECTRONICS



IMEC MAGAZINE

MONTHLY MAGAZINE AS APP

- App for iOS & Android
- Website magazine.imec.be
- Available in English & Dutch
- Look for 'imec int' in the app store

IMEC'S CLEANROOM

TAKE A VIRTUAL TOUR AROUND IMEC'S CLEANROOM

- Discover the most important steps of the chip fabrication process
- App available for iOS & Android
- Look for 'imec's cleanroom' in the app store

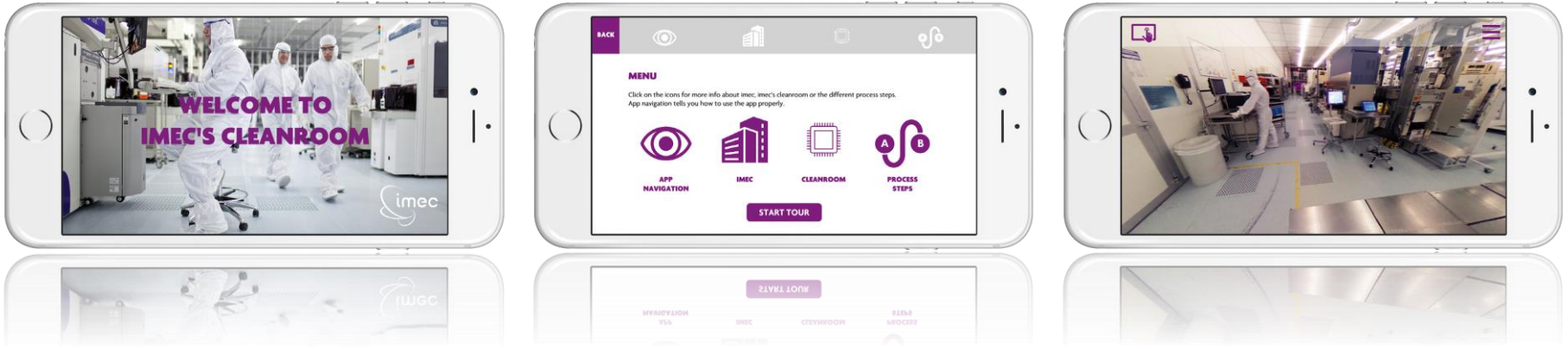


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IMAGE SENSORS

WORKSHOP

Intelligent Systems for a More Connected World

WHAT ARE INTELLIGENT SYSTEMS?

Intelligent Systems are devices that transform how we travel, shop, make things and more.

Connected
Shares data through Internet and the cloud

Managed
Can be remotely monitored, updated and power controlled

Secured
Protects data against malware, theft and tampering

7 Connected Devices per Person

By 2020 each person will own an average of 7 connected devices[1].

COMMUNICATIONS

#2 Data Breach

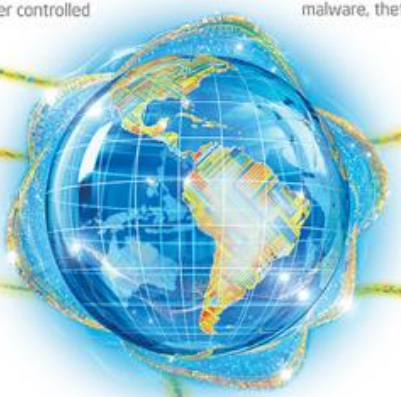
Medical data disclosure is the second most breached source of data[2].

MEDICAL

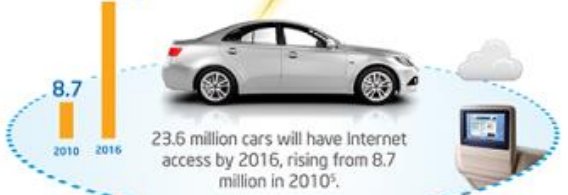
71% of Shoppers are Multi-Channel...

based on respondents planning their 2011 holiday shopping[3].

RETAIL



23.6M Connected Cars



23.6 million cars will have Internet access by 2016, rising from 8.7 million in 2010[5].

VEHICLES

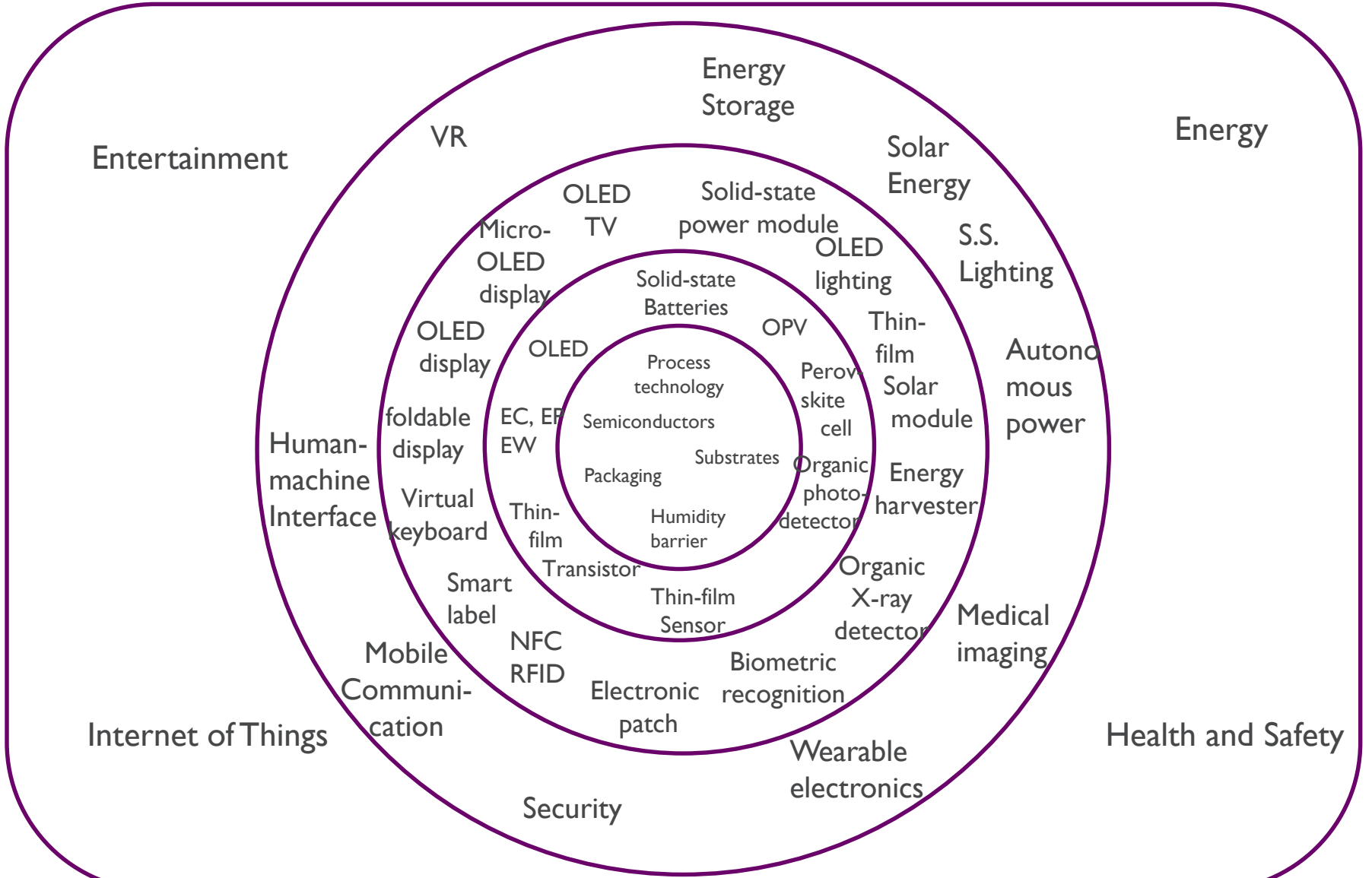
30% Annual Growth Rate

Projected increase in connected machine-to-machine devices over the next 5 years[4].

INDUSTRIAL

1) Cisco, "The Internet of Things: How the Next Evolution of the Internet Is Changing Everything", April 2011
2) Bloor Research, "Security challenges in the US healthcare sector" White Paper, December 2010, http://www.mcafee.com/us/resources/white-papers/wp-bloor-healthcare-security.pdf
3) Deloitte U.S., 2011 Annual Holiday Survey, http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/Consumer%20Business/us_retail_AnnualHolidaySurvey_2011_pr_102611.pdf
4) McKinsey Global Institute analysis, "Big data: The next frontier for innovation, competition, and productivity", June 2011)
5) Wall Street Journal, http://online.wsj.com/article/SB10001424052702304066504576349763614933044.html, estimate from research firm, Frost & Sullivan

intel
Intelligent Systems


Energy Storage
Energy
Entertainment
VR
Solar Energy
S.S. Lighting
Autono mous power
Human-machine Interface
Virtual keyboard
Smart label
Mobile Communi-cation
Internet of Things
NFC RFID
Electronic patch
Biometric recognition
Wearable electronics
Security
Medical imaging
Health and Safety
Energy harvester
Organic X-ray detector
Micro-OLED display
OLED TV
Solid-state power module
OLED lighting
Thin-film Solar module
Organic photo-detector
Thin-film Sensor
Thin-film Transistor
EC, EP EW
foldable display
OLED display
Solid-state Batteries
OPV
OLED
Perov skite cell
Process technology
Semiconductors
Substrates
Packaging
Humidity barrier

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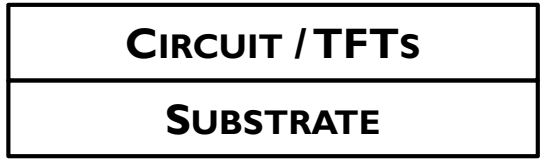


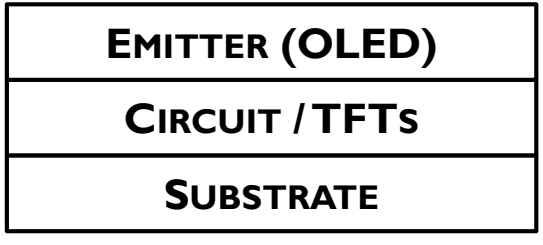
CIRCUIT

LARGE AREA ELECTRONICS

CIRCUITS

DISPLAYS

IMAGE SENSORS



DISPLAY

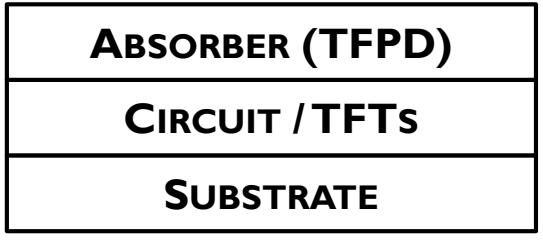
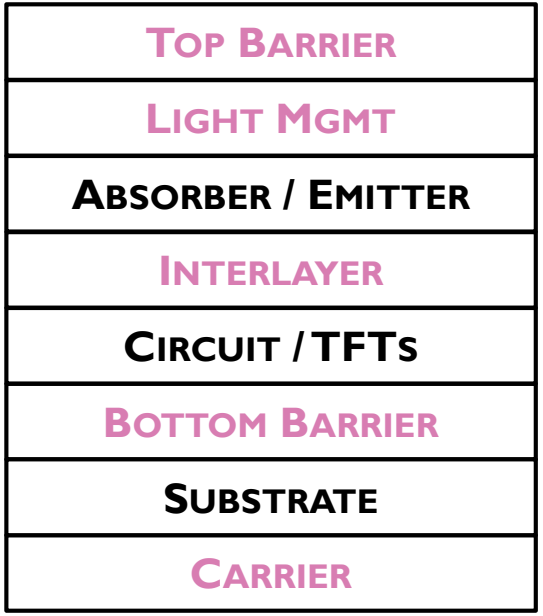
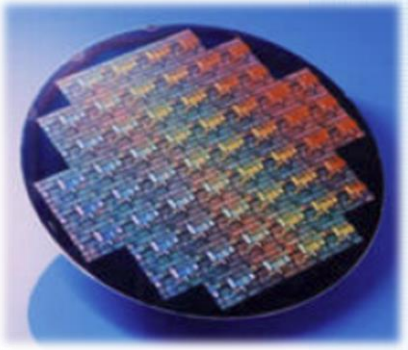


IMAGE SENSOR

Large Area Electronics



COMPARING TRANSISTOR TECHNOLOGIES



Conventional Silicon
- **$40.000/m²**
- X-Si
- 300 mm wafer
- 32 nm

Conventional LCD
- **$200/m²**
- a-Si/poly-Si
- 2x3 m glass plate
- 3 µm

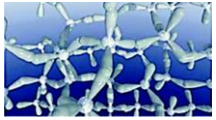
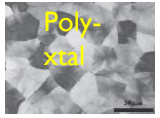
High quality printing
- **$0.25/m²**
- Ink
- 2x ∞ m roll-to-roll
- 20 µm

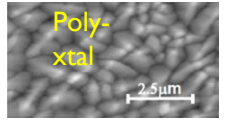
Source: Samsung

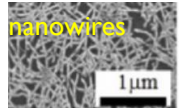
SHEET-2-SHEET DISPLAY FAB

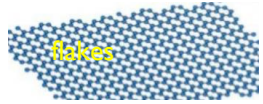
Standard a-Si backplane production

72,000 substrates per month
Investment:~ $4.25B



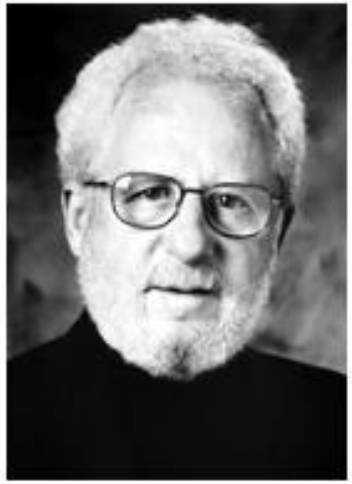




Semiconductor	Amorphous Si	LTPS	Amorphous Oxide	Organic	Carbon Nanotube	Graphene (MoS2, WSe2)
Structure	amorphous					
Mobility cm2/Vs	0.5	100	10...30(...50)	0.3...10(...30)	1000-10.000 (0.1-100 in film)	~10.000
Carrier type	N-type	P+N type	N-type	P-type (some N)	N-type	ambipolar
Uniformity/Size	Excellent/G10	Poor/G4.5	Good/G6	?	poor	?
# masks	4-5	6-11	4-6	4-6	?	?
Temperature	350	450 (and up)	350	100	100	? (quality and T are related)
Cost/yield	Low/high	High/medium	Low/medium	?	?	?
Use	LCD TV	Mobile OLED Mobile LCD	OLED TV LCD TV	-	-	-
R&D hot topic	-	(Uniformity Upscale)	Bias stress P-type oxides	Integration Contacts Mobility	Scaling Turn-off Uniformity	Integration Contacts Dielectrics

ORGANIC SEMICONDUCTOR

Nobel Prize Chemistry 2000



Alan J. Heeger
Prize share: 1/3

Alan G. MacDiarmid
Prize share: 1/3

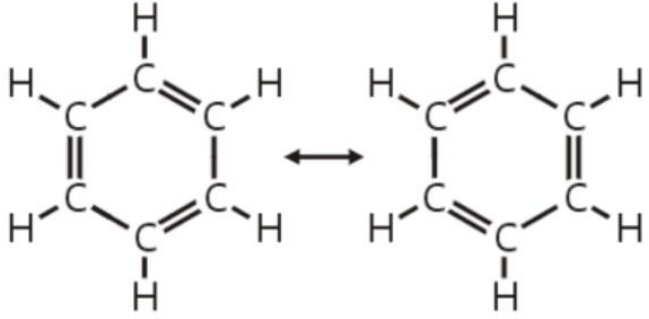
Hideki Shirakawa
Prize share: 1/3

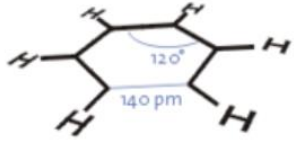
The Nobel Prize in Chemistry 2000 was awarded jointly to Alan J. Heeger, Alan G. MacDiarmid and Hideki Shirakawa *"for the discovery and development of conductive polymers"*.

ORGANIC SEMICONDUCTOR

Based on carbon sp2 hybridization

C_6H_6

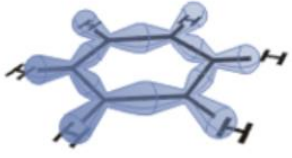




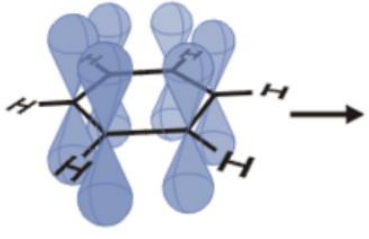
formula

isomers

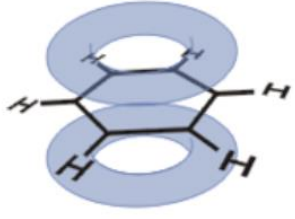
Planar molecule



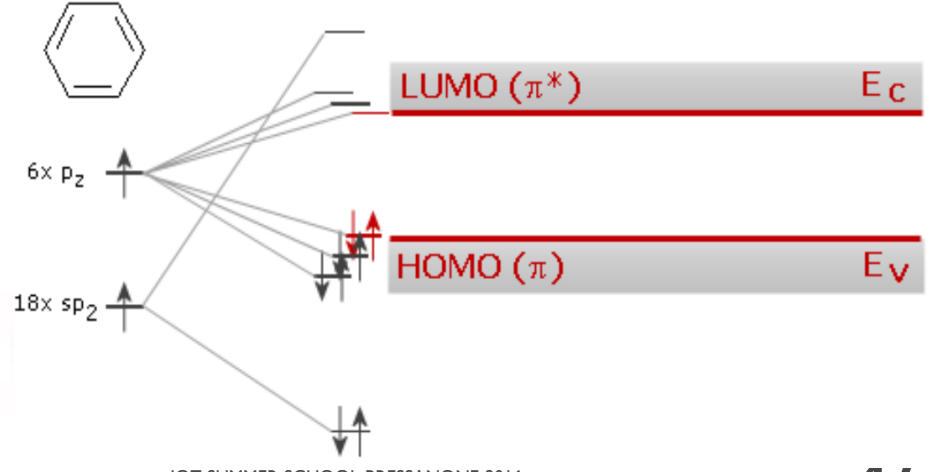
Sigma bond:
sp2 hybridized
orbitals



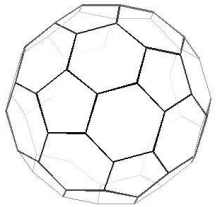
6 p_z orbitals



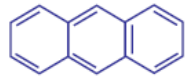
Form delocalized
pi-bond



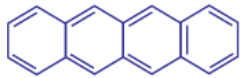
INFINITE NUMBER OF ORGANIC SEMICONDUCTORS



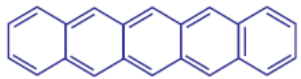
Organic molecules



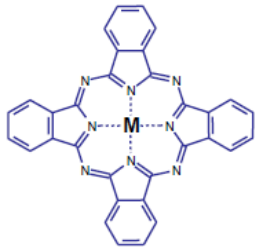
Antracene



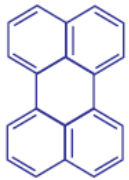
Tetracene



Pentacene

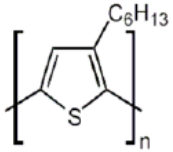


Phthalocyanine

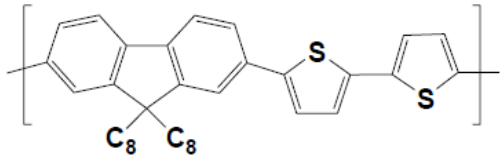


Perylene

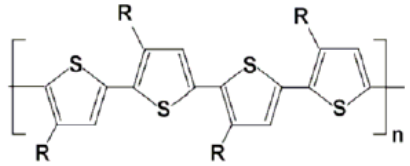
Polymers



Poly(3-hexyl thiophene) (P3HT)



poly(9,9-dioctylfluorene-co-bithiophene) (F8T2)



XPT: regio-regular poly(thiophene)

KEY CHARACTERISTICS: ORGANIC SEMICONDUCTORS

Every molecule in a film is a perfect nano-piece of semiconductor, without dangling bonds or imperfections.

Organic semiconductors **can be grown as thin films on ANY substrate**: their structure is NOT templated by a substrate crystal!

- Glass, Plastic, Insulators, Other organic semiconductors

Organic semiconductors **can be mixed at molecular level**: each molecule remains a perfect piece of semiconductor

- Doping, Bulk Heterojunctions

Organic semiconductors **have low gravimetric density**

- Low: refractive index, dielectric constant, effective density of states, specific weight; strong exciton binding

Organic semiconductors **have large absorption coefficient for light**

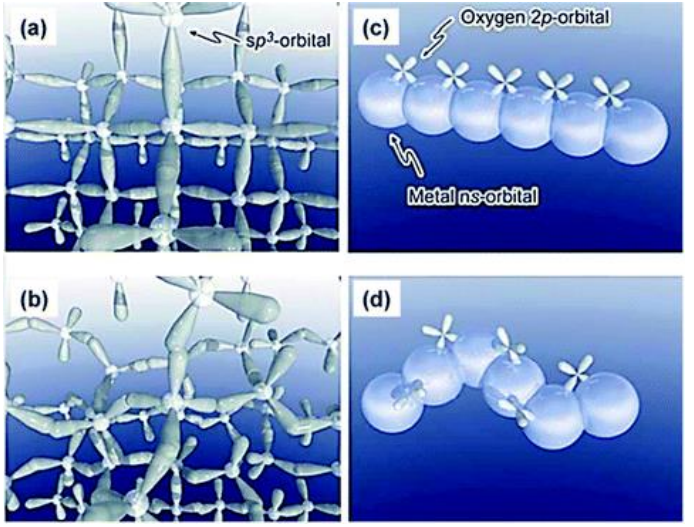
- Molecular absorption: $\alpha = (10^4) - 10^5 - (10^6)\ cm^{-1}$

Organic semiconductors **have usually a large bandgap**

- Visible light, High-lying LUMO (conduction band), Difficult electron injection, Fragile against oxidation during operation

THE SUCCESS OF AMORPHOUS OXIDE SEMICONDUCTORS (AOS)

IGZO (and other Amorphous Oxide Semiconductors) DELOCALIZED electrons in the conduction band despite amorphous structure, which is highly appreciated for achieving good uniformity over arbitrary large areas (Gen 8 today)



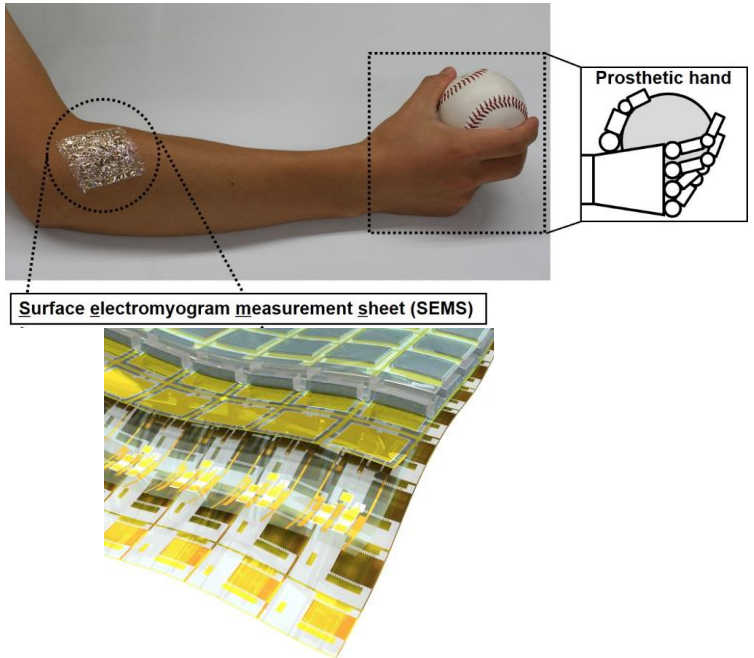
Trends:

- Higher **mobility** (different compositions)
- Higher performance by transistor **architecture** (self-aligned source/drain with respect to gate)
- Finding a matching **p-type oxide** semiconductor material

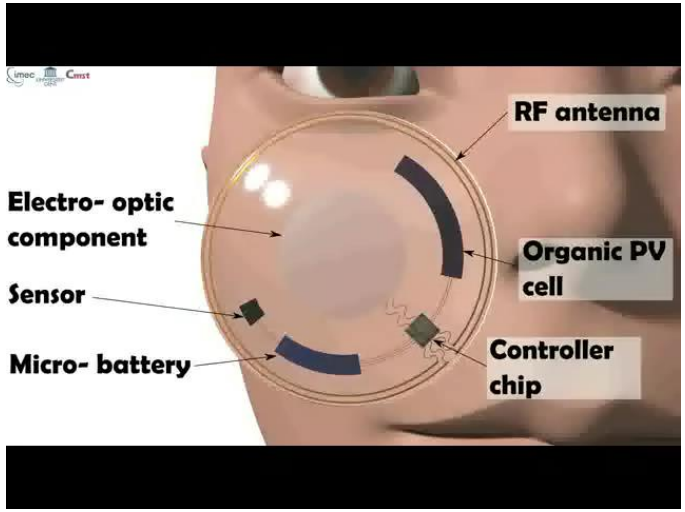
ON-BODY: SKIN PATCHES, CONTACT LENS, …

skin patch (thermometer)

Area skin patch (electromyogram)

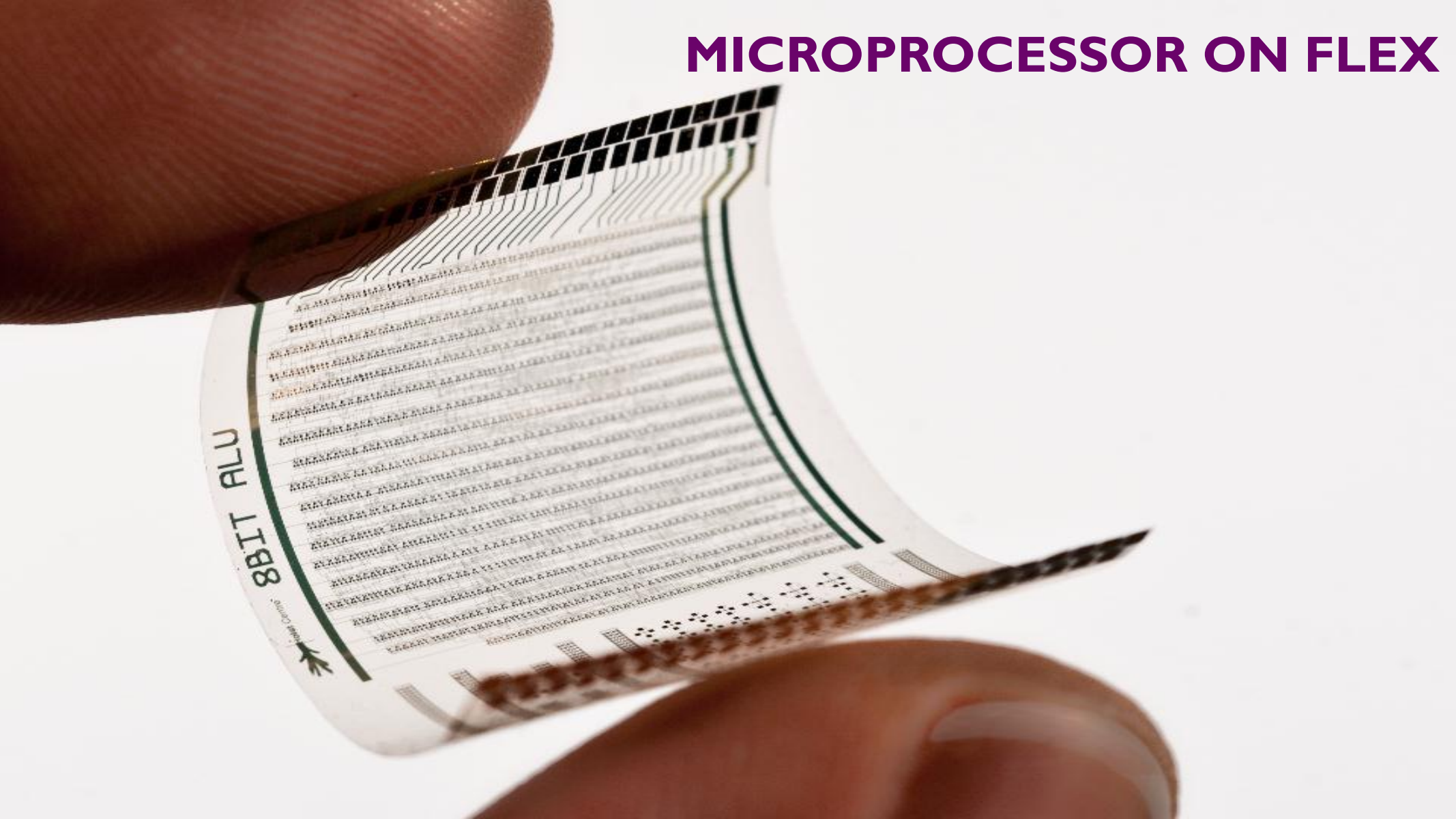


Smart contact lens

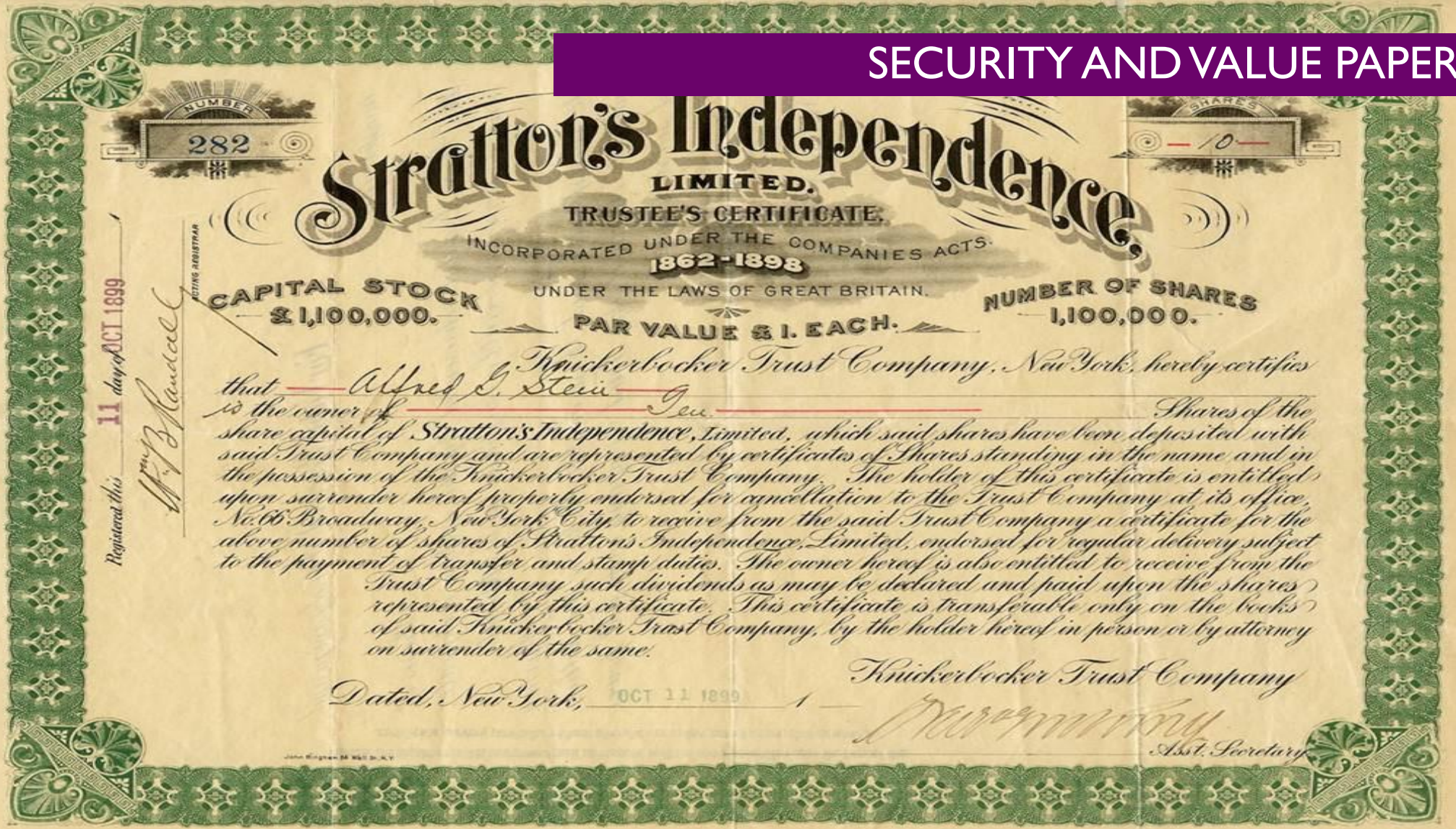


Hiroshi Fuketa et al, ISSCC 2013 Tokyo University

MICROPROCESSOR ON FLEX



WAREHOUSE AND TRANSPORT LOGISTICS



NUMBER 282

SHARES 10

Stratton's Independence,

LIMITED.

TRUSTEE'S CERTIFICATE.

INCORPORATED UNDER THE COMPANIES ACTS 1862-1898

UNDER THE LAWS OF GREAT BRITAIN.

CAPITAL STOCK £1,100,000.

PAR VALUE £1. EACH.

NUMBER OF SHARES 1,100,000.

Registered this 11 day of OCT 1899

ACTING REGISTRAR

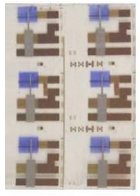
The Knickerbocker Trust Company, New York, hereby certifies that Alfred G. Stein Jen. is the owner of Shares of the share capital of Stratton's Independence, Limited, which said shares have been deposited with said Trust Company and are represented by certificates of Shares standing in the name and in the possession of the Knickerbocker Trust Company. The holder of this certificate is entitled upon surrender hereof properly endorsed for cancellation to the Trust Company at its office, No. 66 Broadway, New York City, to receive from the said Trust Company a certificate for the above number of shares of Stratton's Independence, Limited, endorsed for regular delivery subject to the payment of transfer and stamp duties. The owner hereof is also entitled to receive from the Trust Company such dividends as may be declared and paid upon the shares represented by this certificate. This certificate is transferable only on the books of said Knickerbocker Trust Company, by the holder hereof in person or by attorney on surrender of the same.

The Knickerbocker Trust Company

Dated, New York, OCT 11 1899

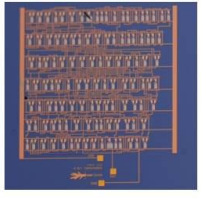
Asst. Secretary

IMEC IOT CIRCUIT TRACK RECORD


NatureMaterials 2005
UHF rectifiers
IEDM 2008


64bit plastic RFID tag
ISSCC 2008

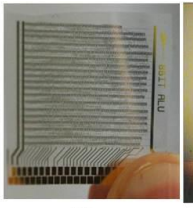

128b
ISSCC 2009


50 kb/s
IEDM 2009

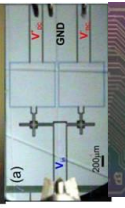

6b AD
ISSCC 2010


DC-DC
ESSCIRC 2010


Low V 64 b transponder
ISSCC 2010


8b microprocessor
ISSCC 2011

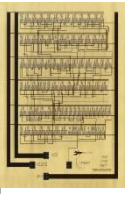

Bi-di RFID
ISSCC 2012


UHF rectifiers
IEDM 2013


8b hybrid μP
ISSCC 2014


Ultralow Power RFID
IEDM2014


Oxide NFC
ISSCC 2015


SA NFC
ISSCC 2016

General purpose, programmable processor


Myny *et al.*, ISSCC 1011
Myny *et al.*, ISSCC 2014

IoT

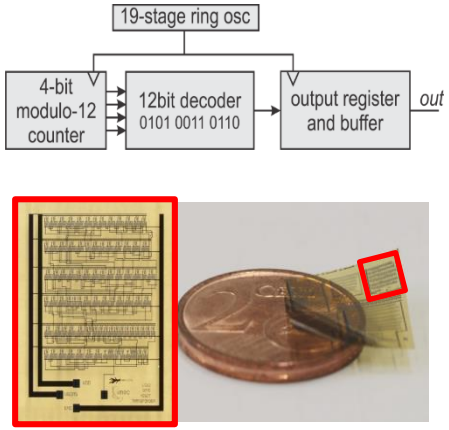
Oxide NFC chip

Myny *et al.*, ISSCC 2015
Myny *et al.*, ISSCC 2016

APPLICATION CASE: GAMES

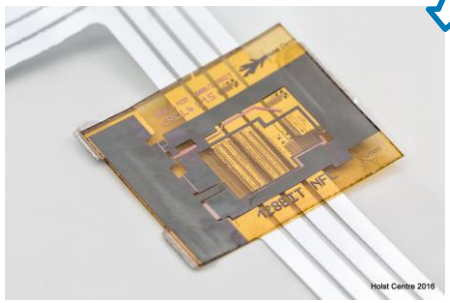
12-BIT THIN-FILM TAG

Thin-film IC



- 438 n-type transistors
- 10.884 mm² chip area
- L = 5µm

Tag



- Thin-film IC
- Plus inductive antena

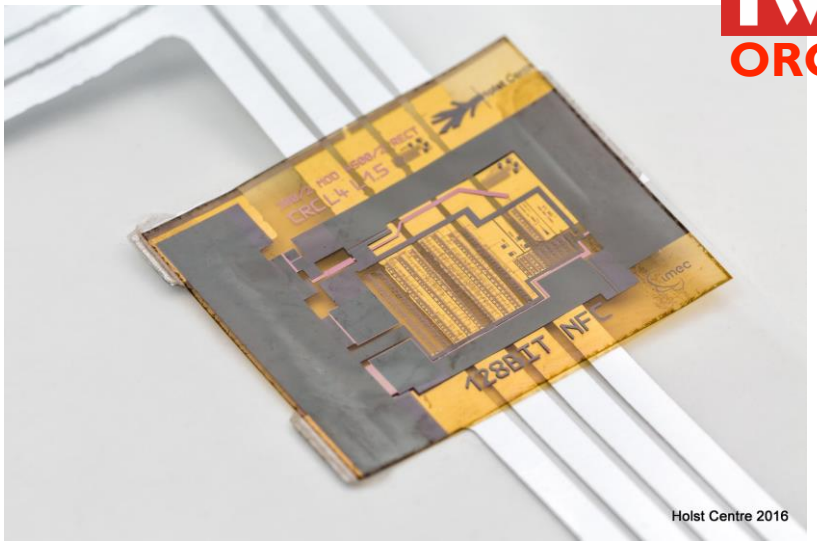
Reader

- RFID reader
- Connected to PC (via USB)

ORCA PROJECT RESULTS

- IWT project ORCA finished
- Final demonstrator:
  - Plastic tags in paper cards (12-bit RFID)
  - Dedicated reader hardware + Game app
- Printed Electronics Europe - Best Product Award
- Next: low-volume prototyping

1. Thin-film IC (example)



2. Card integration

3. Dedicated reader

4. Demo game ("higher-lower")

INTRODUCTION

INTERNET OF THINGS

IMEC

LARGE AREA ELECTRONICS

CIRCUITS

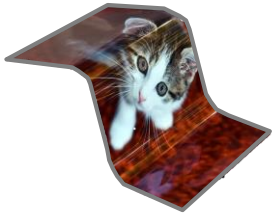
DISPLAYS

IMAGE SENSORS

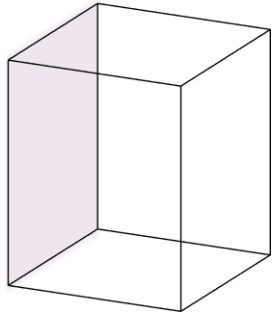
WORKSHOP

DISPLAY TECHNOLOGY - TRENDS

KEY PERFORMANCE INDICATORS FOR DISPLAY APPLICATIONS

Today	Tomorrow	Day After Tomorrow
		
High Resolution 2K, 4K, 8K...	Ultra low Power	Super thin
Thinner & Larger	Physically robust	Roll & flex
Perfect black	Conformal	Stretch
		
Virtual Reality		
Augmented Reality		
 		
"Boxed" or "Flat" 3D or Holograms		
Ultra-high Pixel Resolution		
360 degree viewing angle		

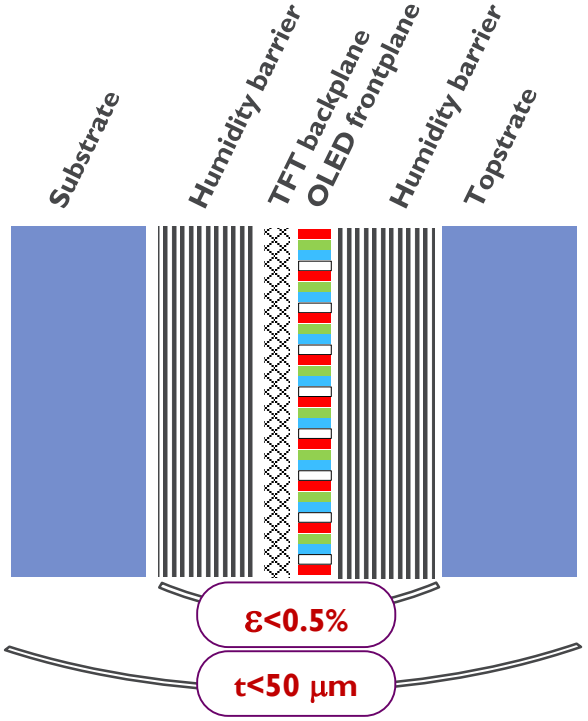
TREND 1: THINNER, LIGHTER DISPLAYS



CRT

30cm

DESIGN AND MANUFACTURABILITY



Ultra-thin **substrate** preferably 3-10 micron

delamination

Ultra-thin display effect **OLED** not LCD

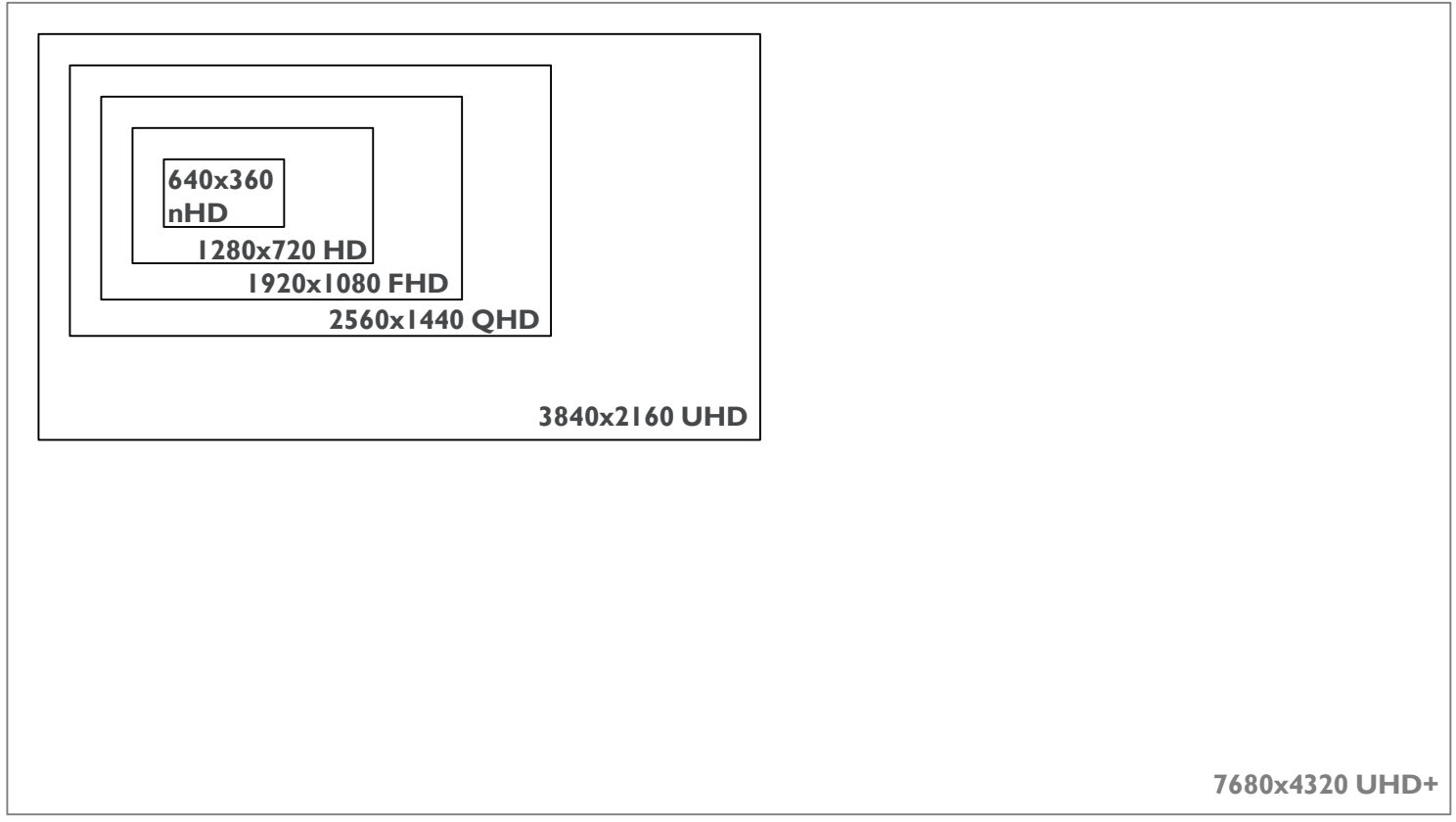
Ultra-thin multi-layer **humidity barrier** (few micron)

materials

High-performance transistors processed on plastic substrate

Full stack robust against **repetitive bending**

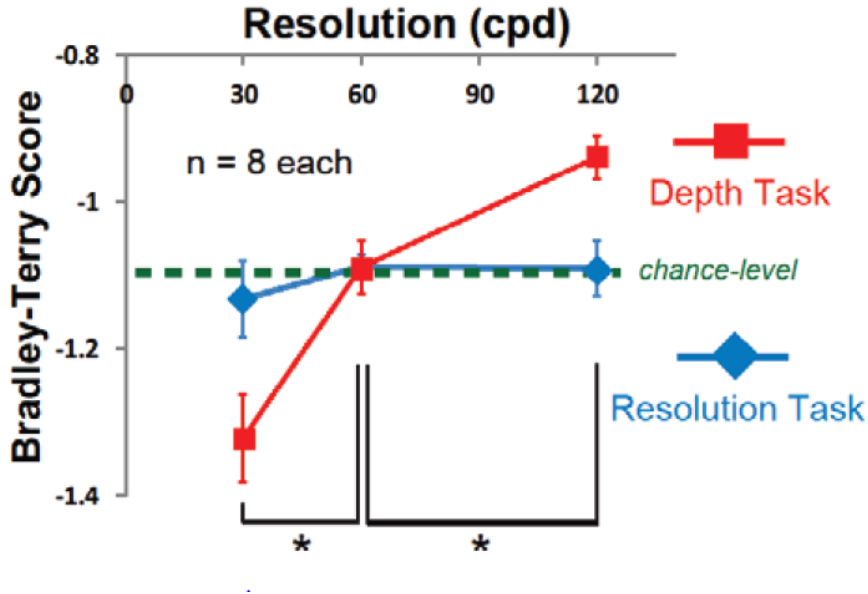
TREND 2: INCREASE IN RESOLUTION



IS THERE A LIMIT TO THE RESOLUTION NEED?

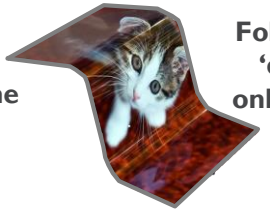
BEYOND RETINA RESOLUTION

"... we found that participants felt stronger depth sensation for higher resolution stimulus without noticing the resolution difference. It indicates that there are two types of visual information in our visual system, consciously available and unavailable information. To investigate what neural mechanism underlies this phenomenon, further research is needed."



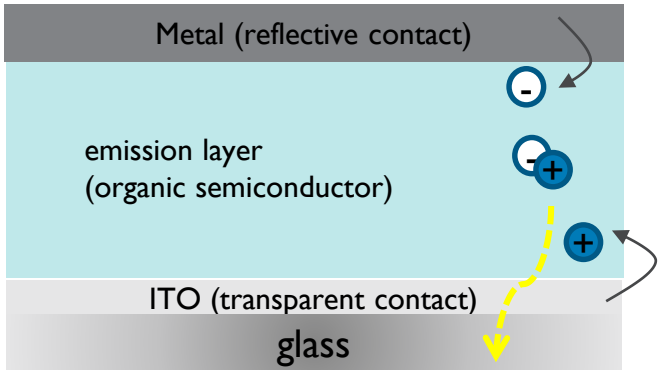
Y. Tsushima *et al.*, "**Super Hi-Vision (8K) Produces Stronger Depth Sensation than 4K and Hi-Vision (2K)**" International Display Workshops IDW 2014, VHF6-4L, Niigata, Japan (2014)

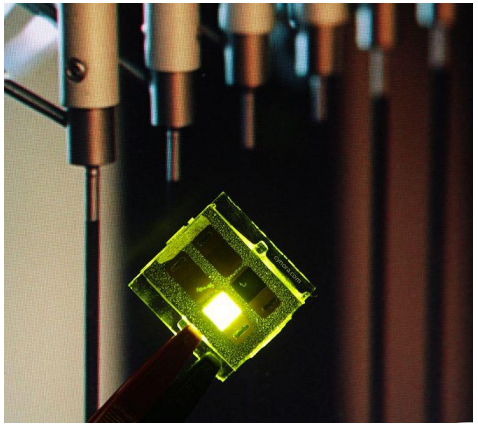
‘DISPLAY’ AS COMMUNICATION PLATFORM

SOUND	 telephone	80 to 93% of information is NON verbal!			
VISION		 Smart phone	 Foldable display ‘disappears’; only the content is central	 Augmented reality	 Full immersion
TOUCH	 Buttons and Dials	 Touch	 Gesture	 Active feedback	 Full haptic

ORGANIC LED BASIC PRINCIPLE

Principle:





Organic semiconductor:

small molecule → vacuum evaporation

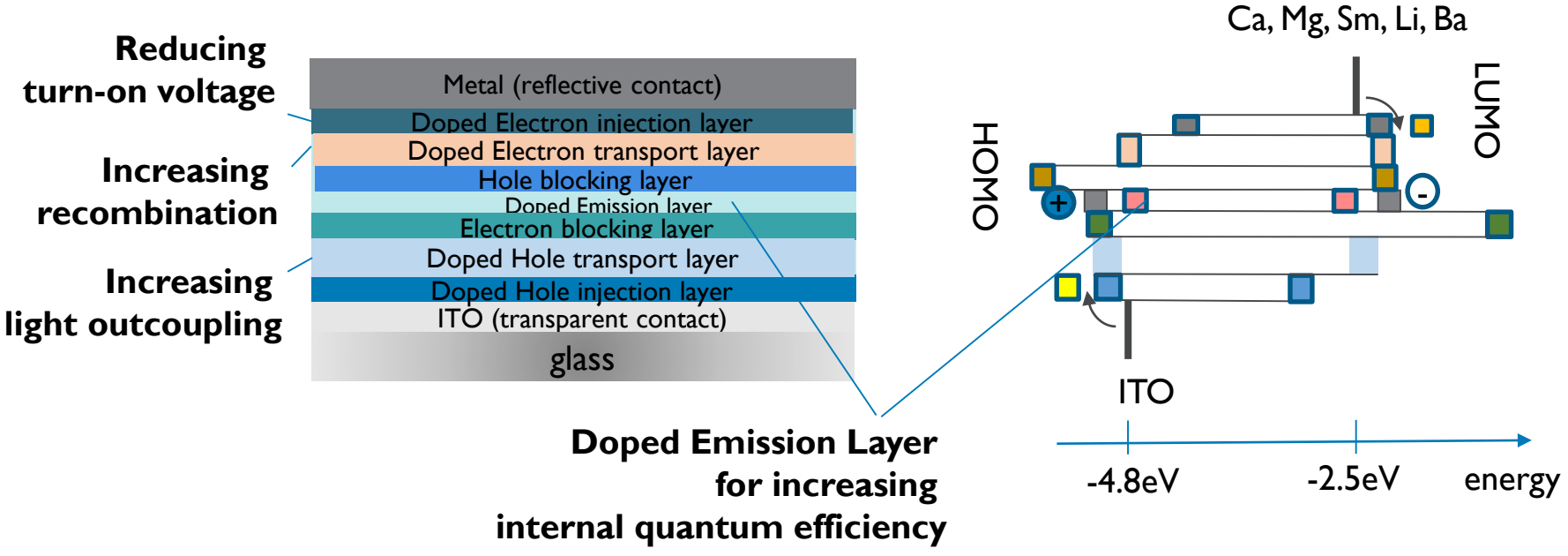
polymer → solution processing

First small molecule OLED in 1987 (Tang et al, APL)

First Polymer OLED in 1990 (Burroughes et al , Nature)

MODERN ORGANIC LED STRUCTURE FOR SINGLE COLOR

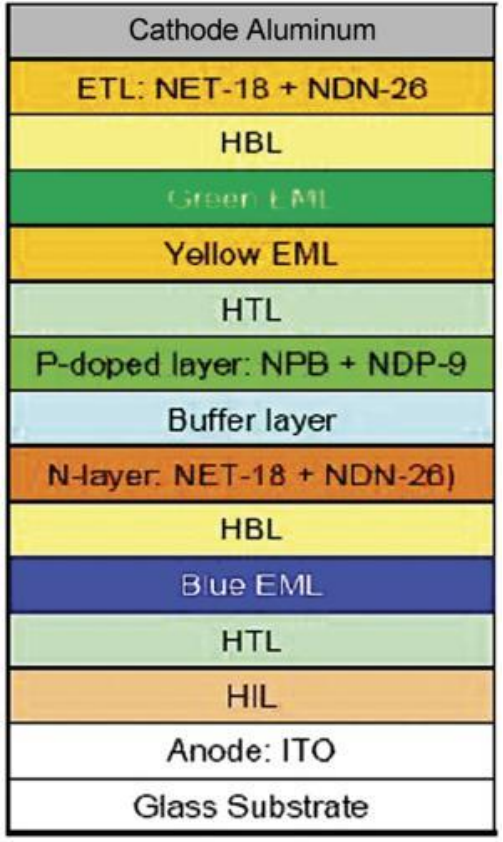
Improved OLED structure:



Single color OLED:

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

MODERN ORGANIC LED STRUCTURE FOR WHITE



e.g. tandem white OLED by Novaled

White OLED:

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

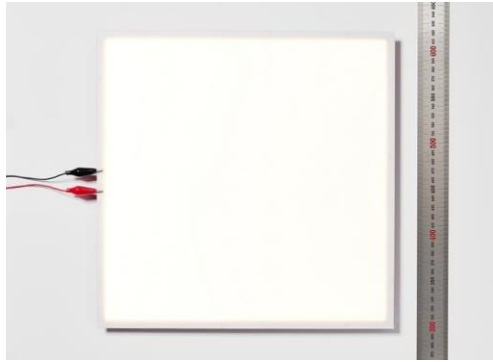
→ 8-15 layers, 20+ materials

OLED USE

200 cd/m^2

200-300 cd/m^2

500-800 cd/m^2

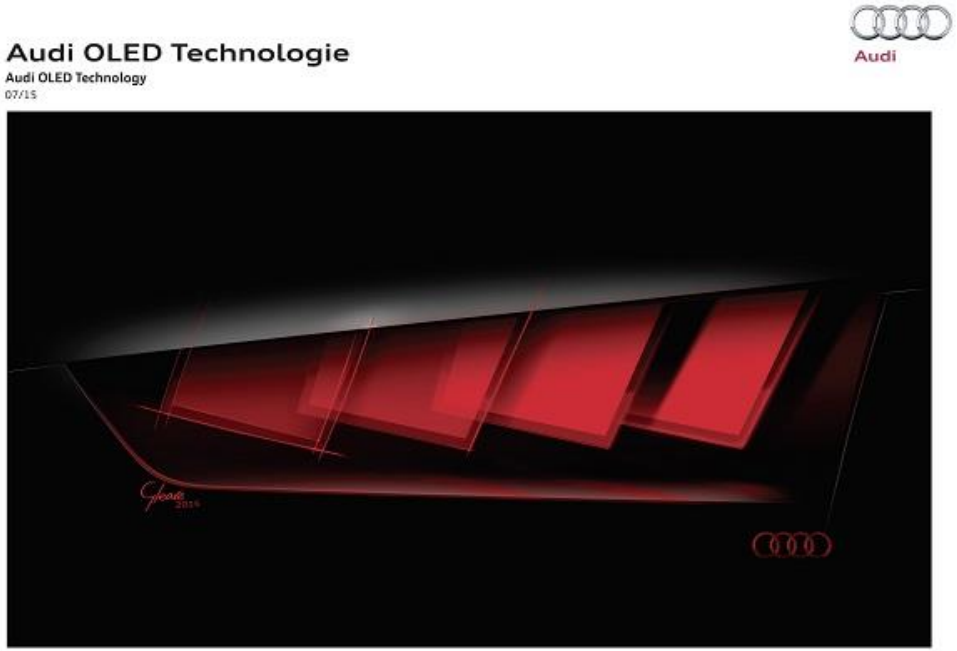


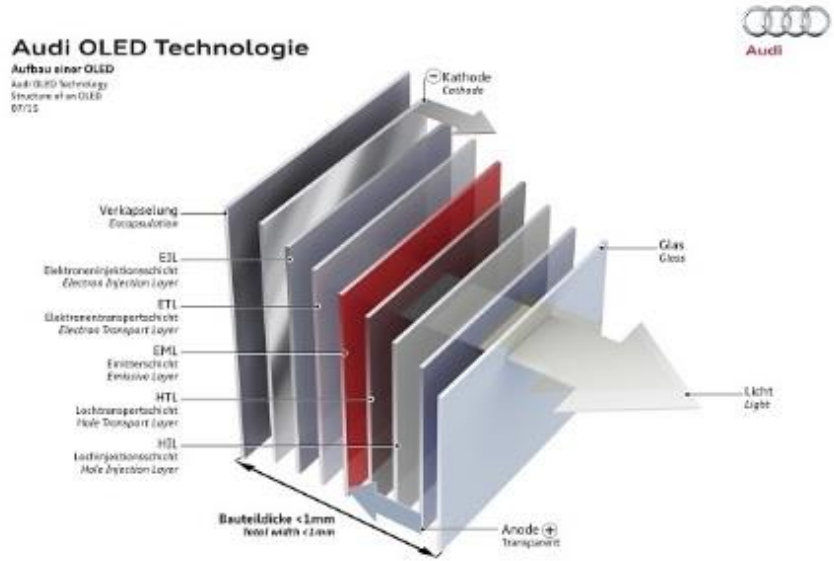
1000-2000 cd/m^2

TREND: THE DIFFERENTIATOR OF OLED LIGHTING IS *FLEXIBLE*

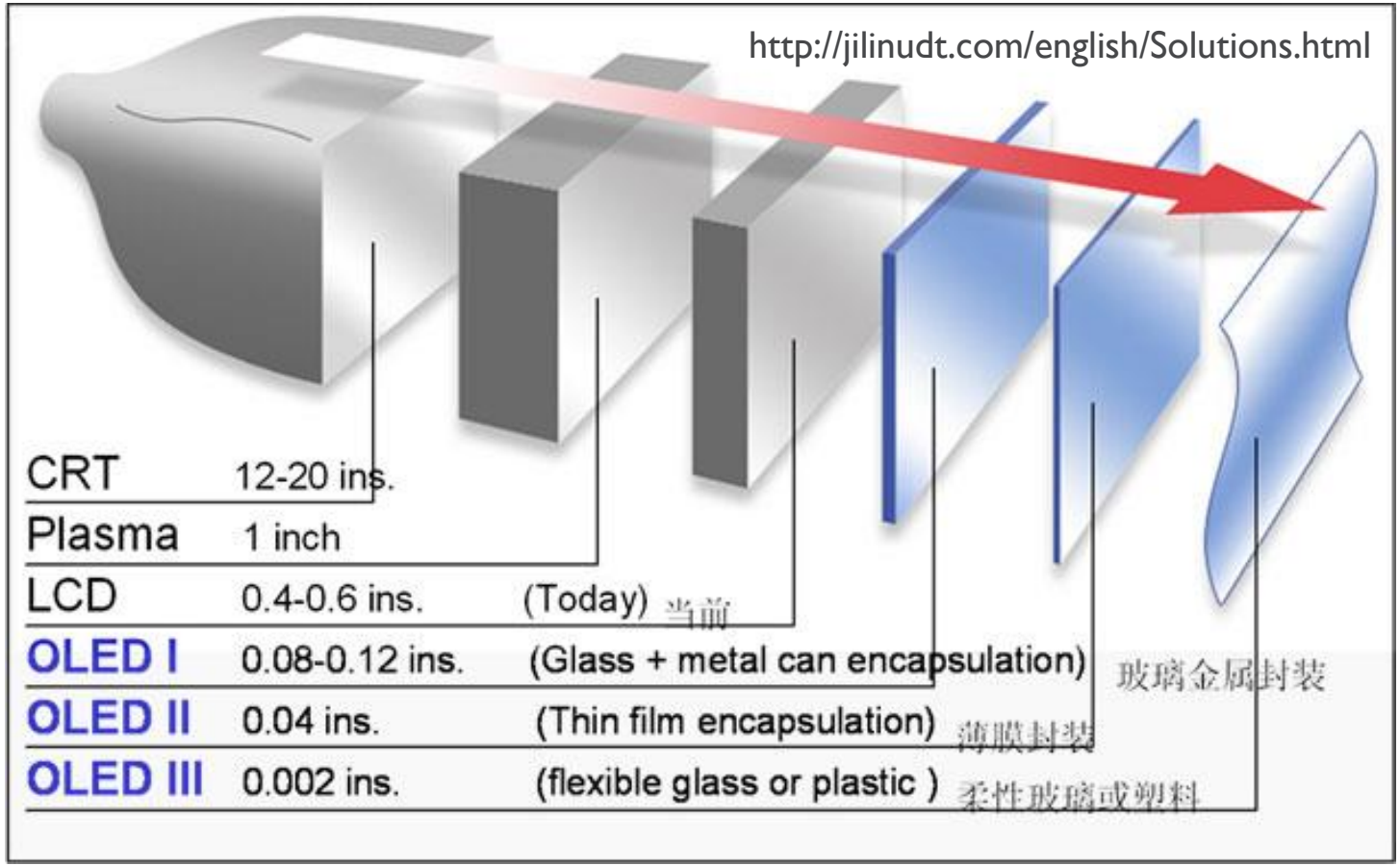
TREND: NEW INTEGRATIONS IN TAILLIGHTS

SEMI-TRANSPARENT, PARTIALLY OVERLAPPING, PIXELATED, ULTRA-THIN, NO COOLING





TREND: TOWARDS THINNER DISPLAYS



http://jilinudt.com/english/Solutions.html

WHERE ARE THE DISPLAYS TODAY?

AMOLED Displays Today

BOE

AMOLED Displays Today

BOE

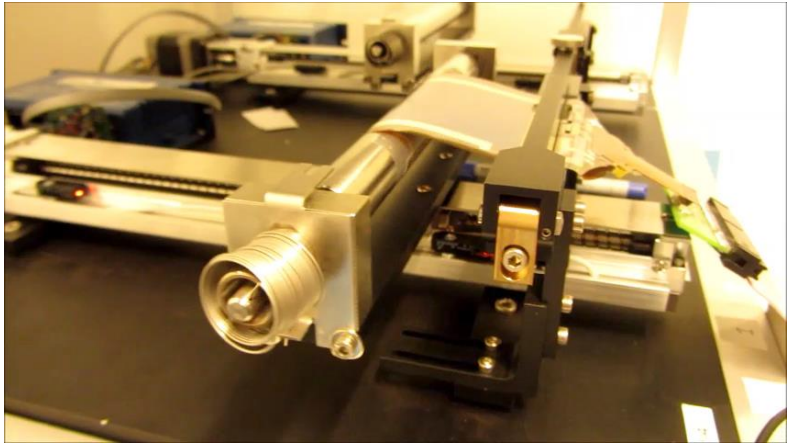
AMOLED Displays Today

LG

AMOLED Displays Today

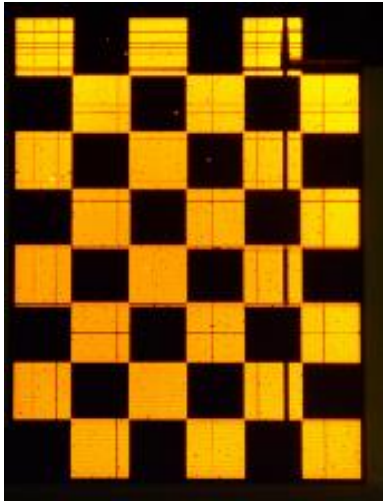
LG

LIFETIME AND ROLLABILITY

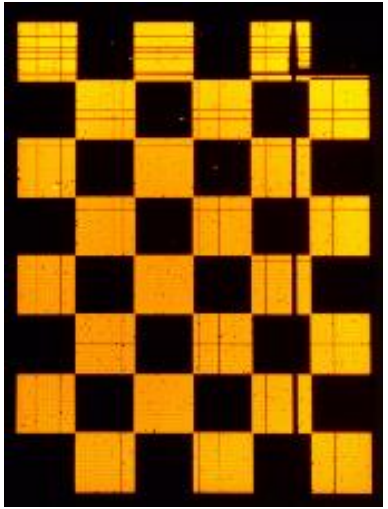


No degradation after
- 100k rolling with radius 1cm
- 2500h @ 60°C/90%RH

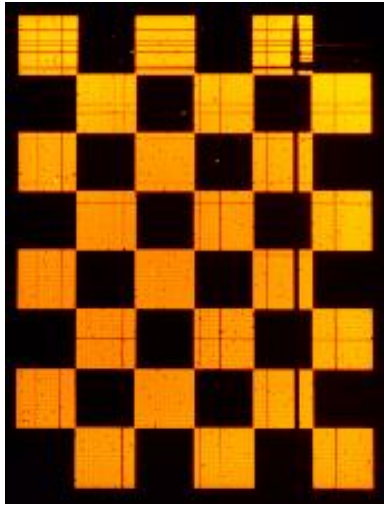
Initial



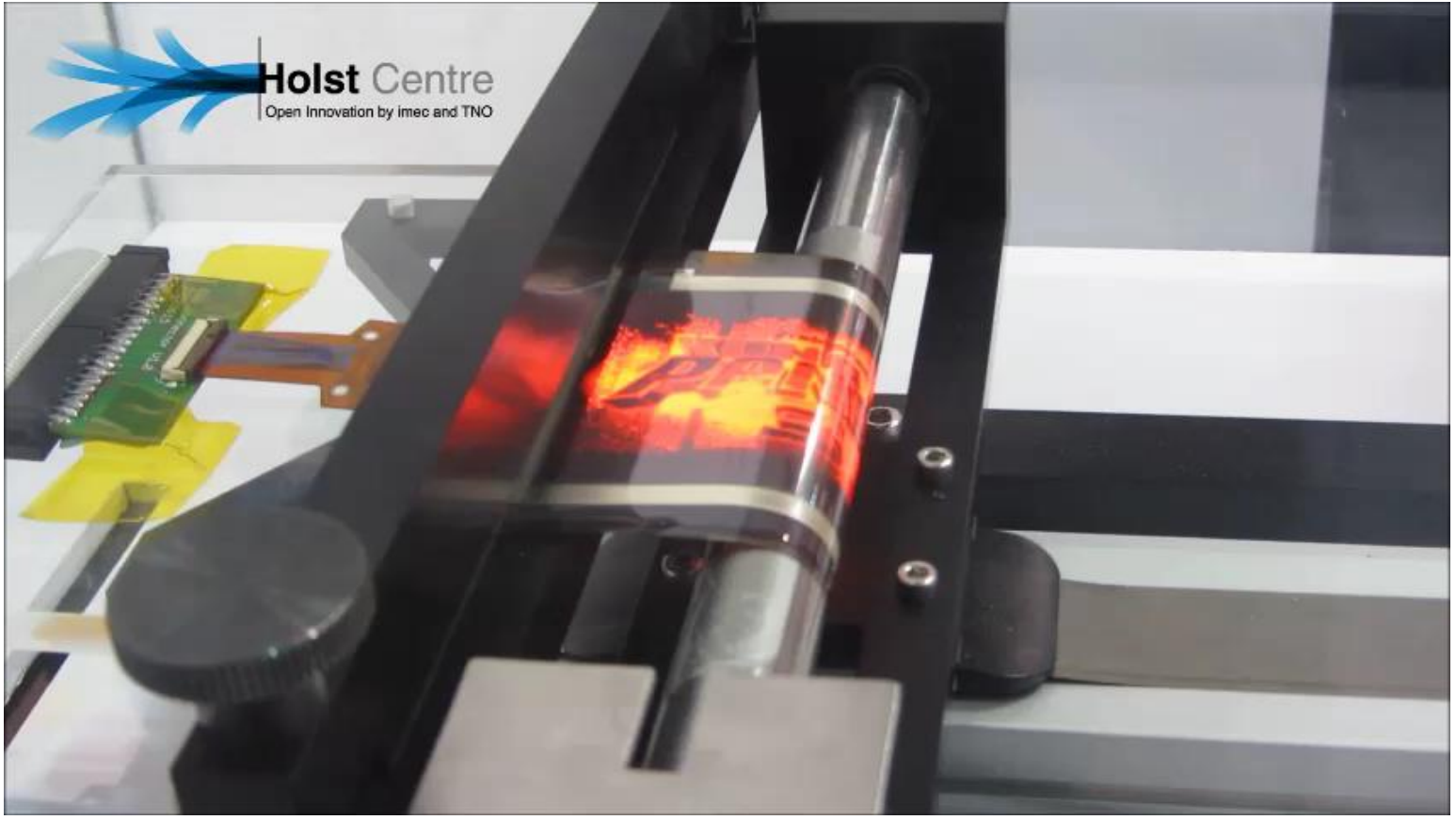
After 10000 rolls



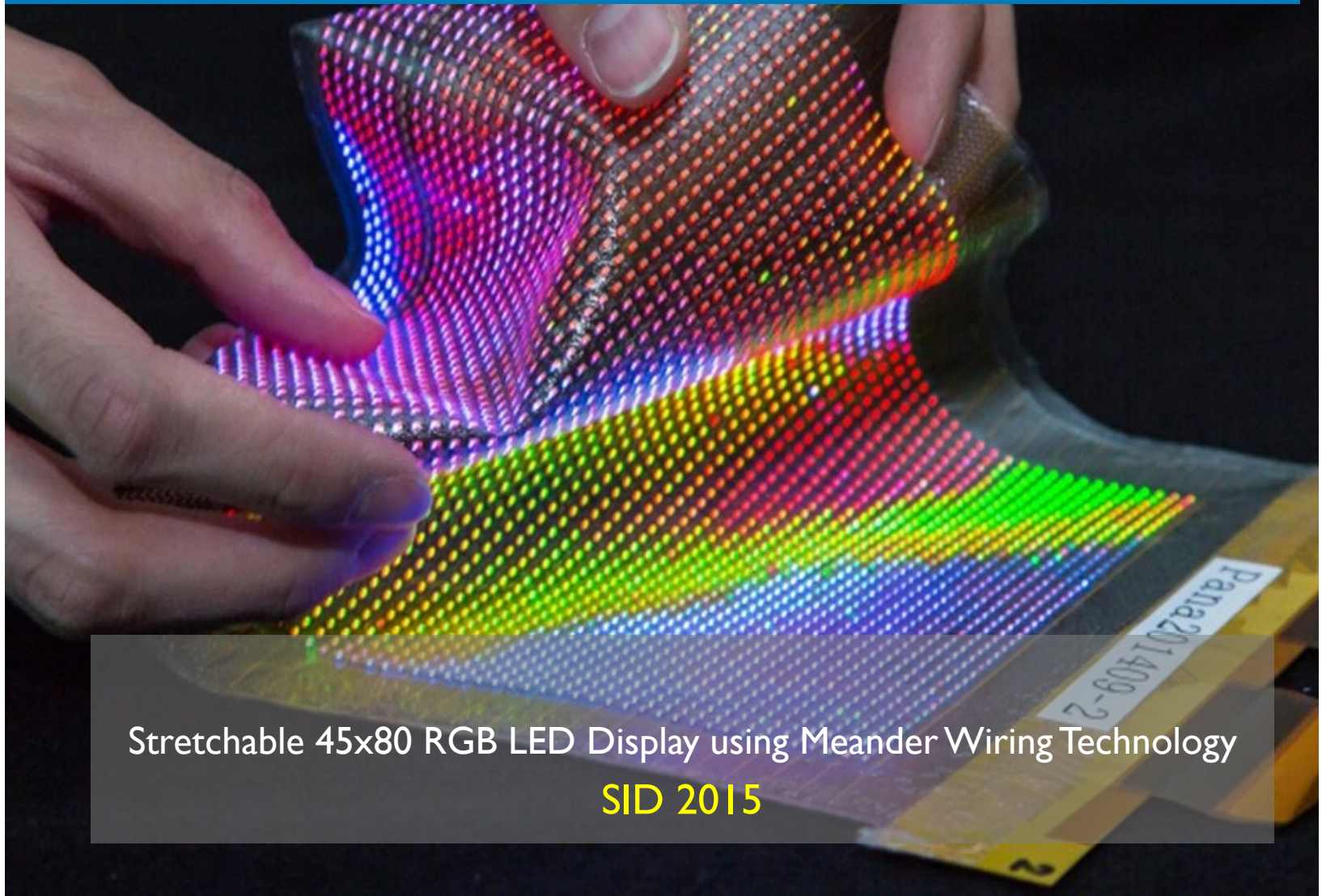
After 30000 rolls



IMEC/HOLST DEMO AT TOUCH TAIWAN, 2015



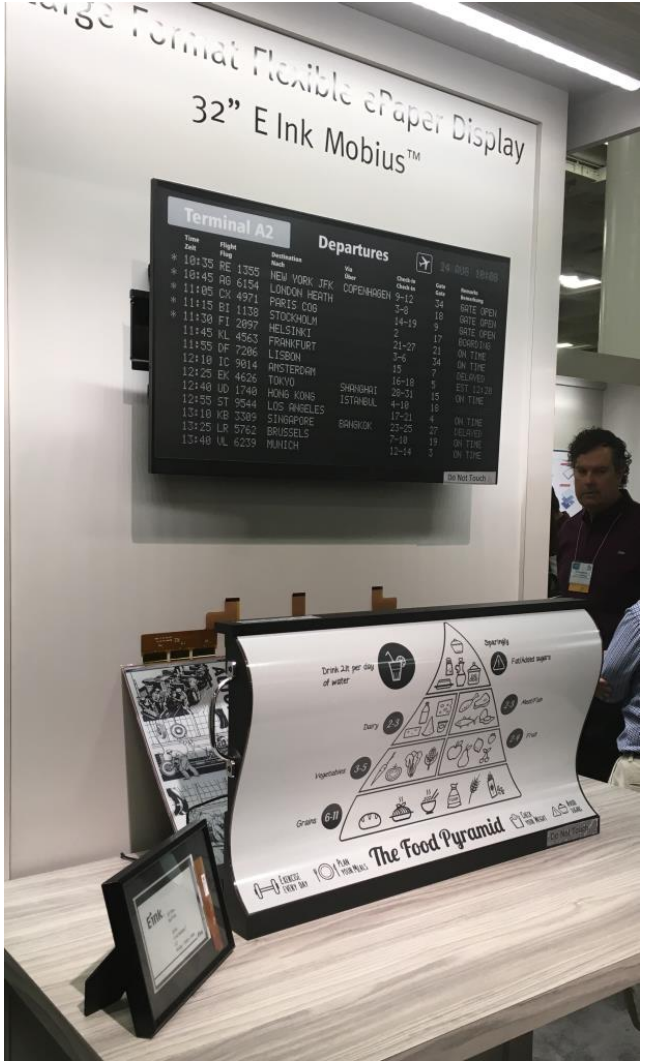
Towards stretchable displays



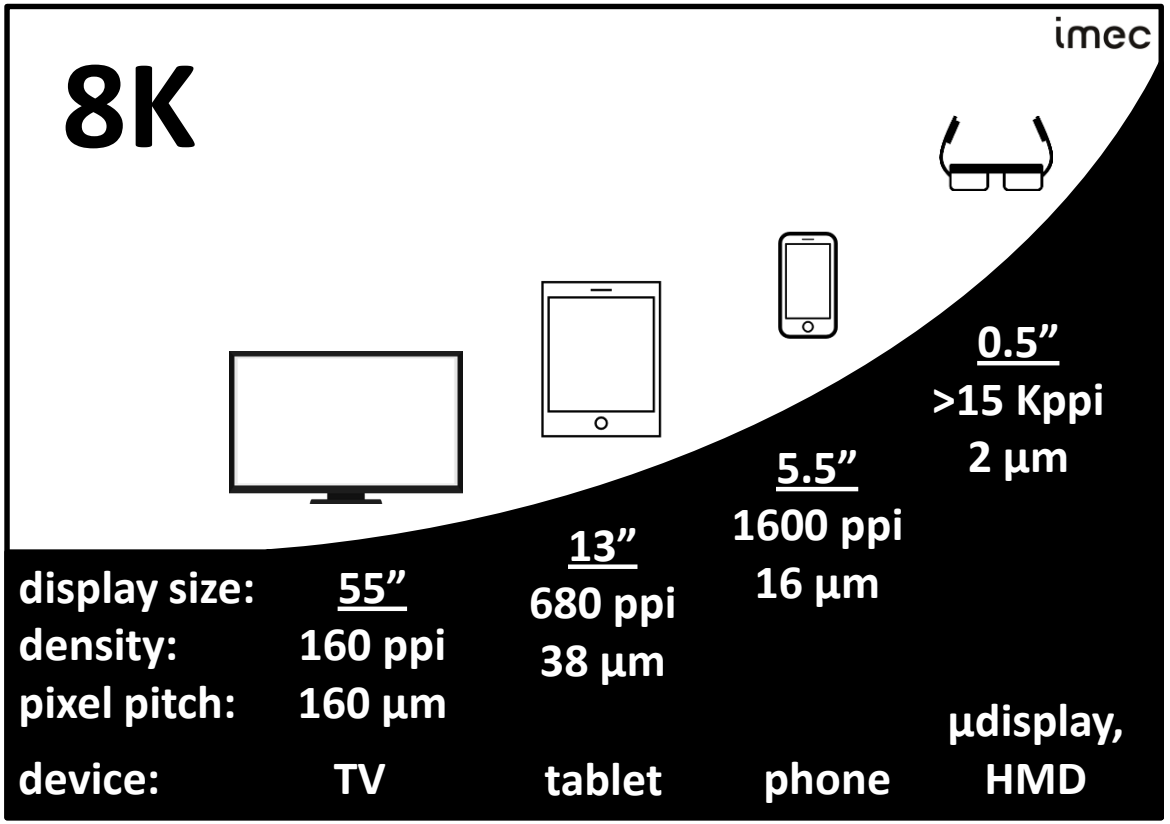
Stretchable 45x80 RGB LED Display using Meander Wiring Technology

SID 2015

E-Ink Displays Today



Small Pixels Needed For 8K Resolution



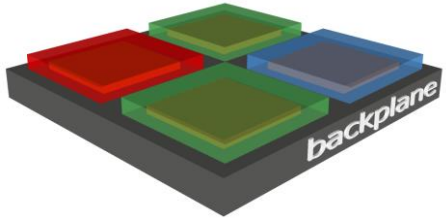
AMOLED Displays

OLED

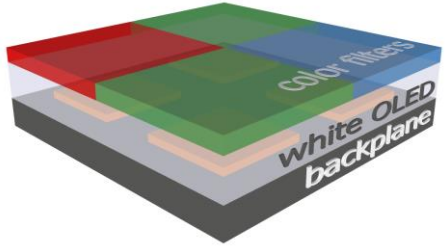
- *thin and light*
- *flexible*
- *power efficient*
- *high contrast*
- *deep black*

RED-GREEN-BLUE OLED FABRICATION

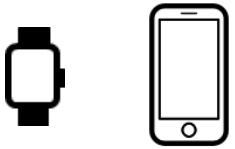
- ***OLED***
  - ***RGB side-by-side***



  - ***color-by-white***

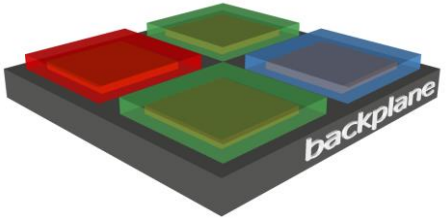


RED-GREEN-BLUE OLED FABRICATION

- *OLED*
  - *RGB side-by-side*  *used for small displays (watch, smartphone)*
  - *color-by-white*  *used for large displays (monitor, TV)*

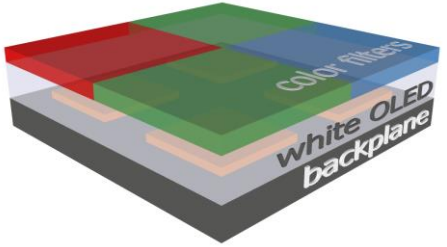
RED-GREEN-BLUE OLED FABRICATION

- *OLED*
  - *RGB side-by-side*



- ✓ *power / efficiency*
- x *resolution*
- x *aperture ratio*
- x *large substrates*

  - *color-by-white*

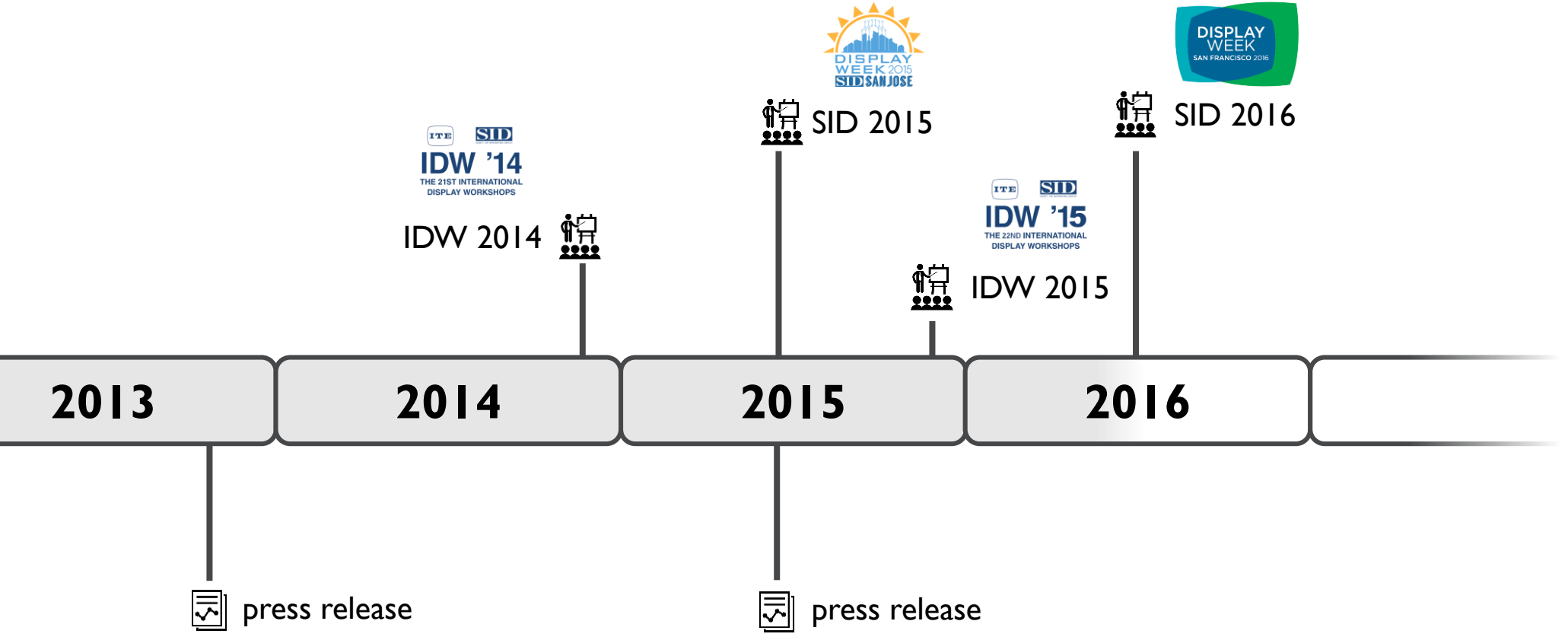


- x *power / efficiency*
- ✓ *resolution*
- ✓ *aperture ratio*
- ✓ *large substrates*

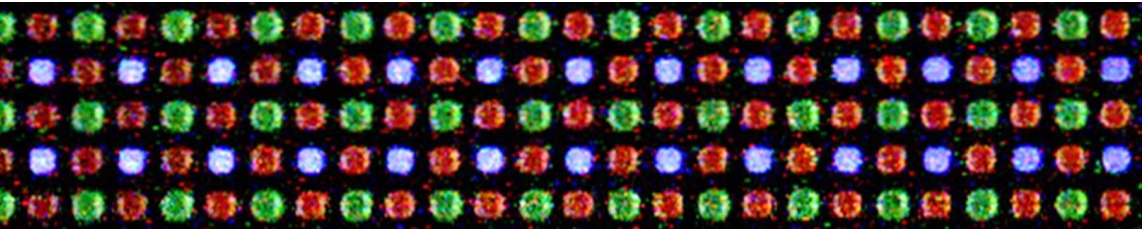
RED-GREEN-BLUE OLED FABRICATION

- *OLED*
  - ***RGB side-by-side***
    - *shadow masking*
    - *(inkjet) printing*
    - *laser transfer*
    - *self assembly*
    - ***photolithography***
      - ✓ ***resolution***
      - ✓ ***aperture ratio***
      - ✓ ***large substrate size***
      - ✓ ***multicolor***
      - x ***chemical compatibility***
  - *color-by-white*

OLED Patterning Milestones at imec



OLED Patterning Milestones at imec



640 ppi RGB OLEDs

blue lifetime 35 h

2013 | 2014 | 2015 | 2016

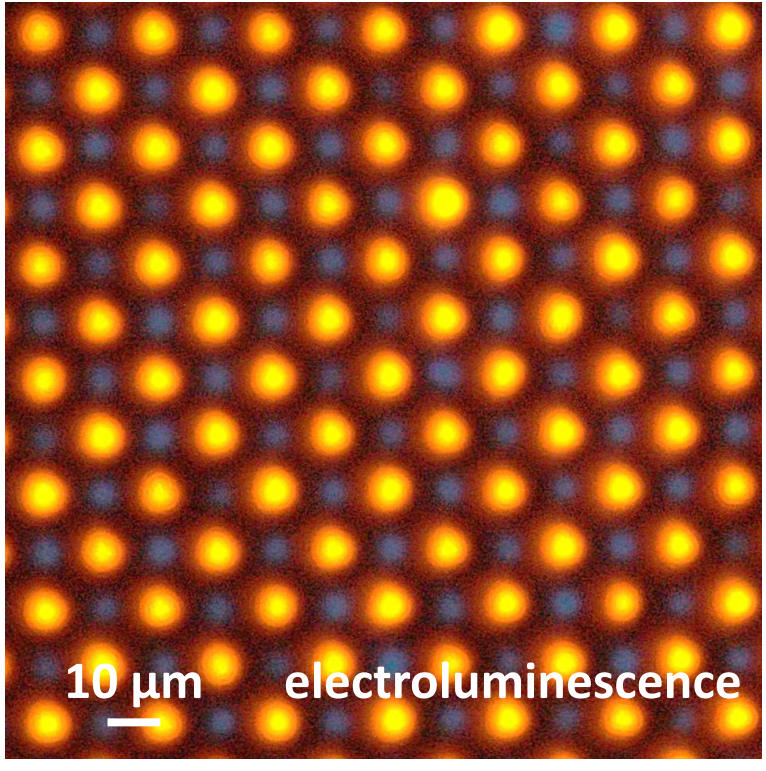
SID 2015

1250 PPI ORANGE/BLUE OLED ARRAYS

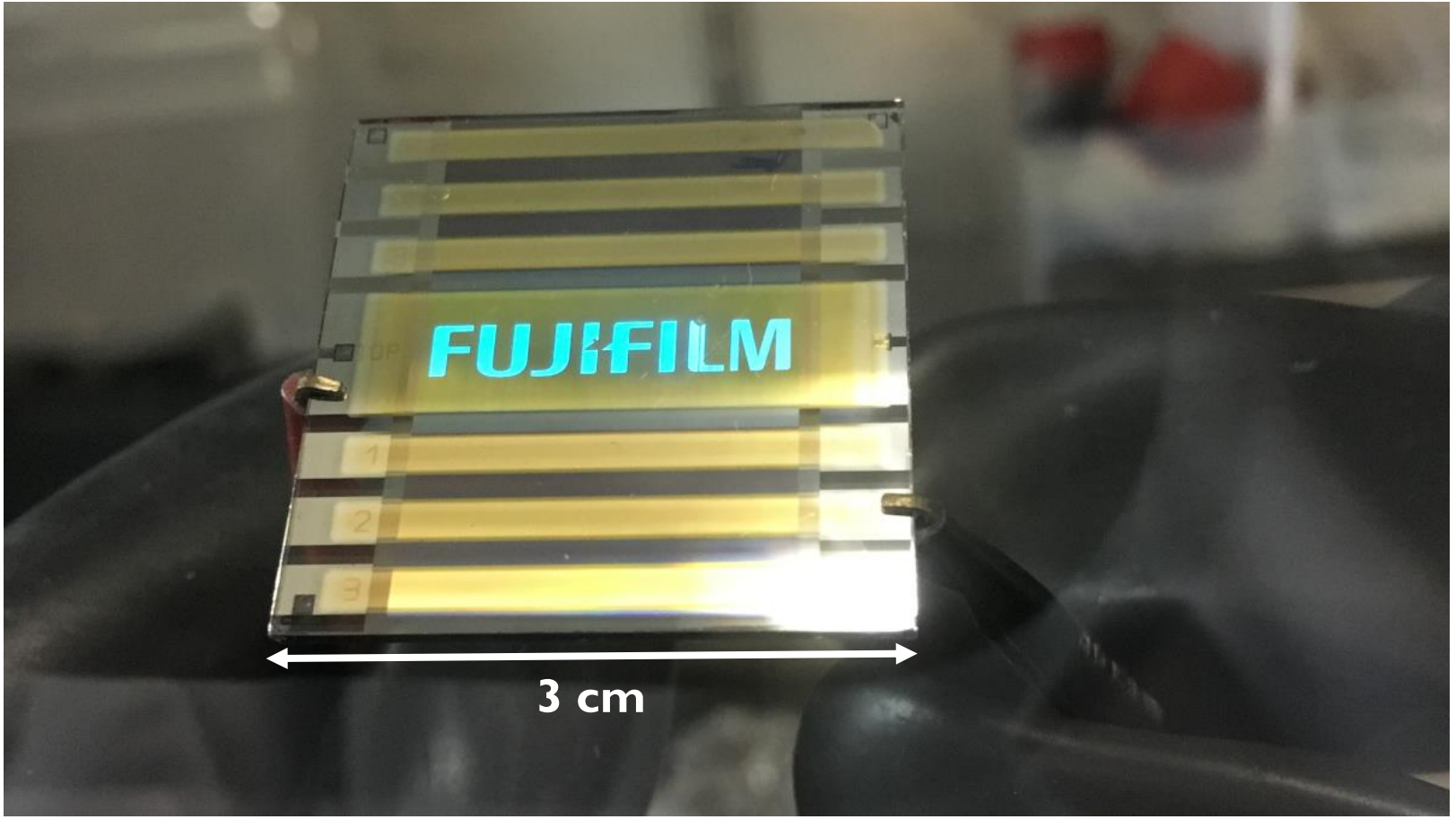
10 µm pixel pitch

80x80 pixel array

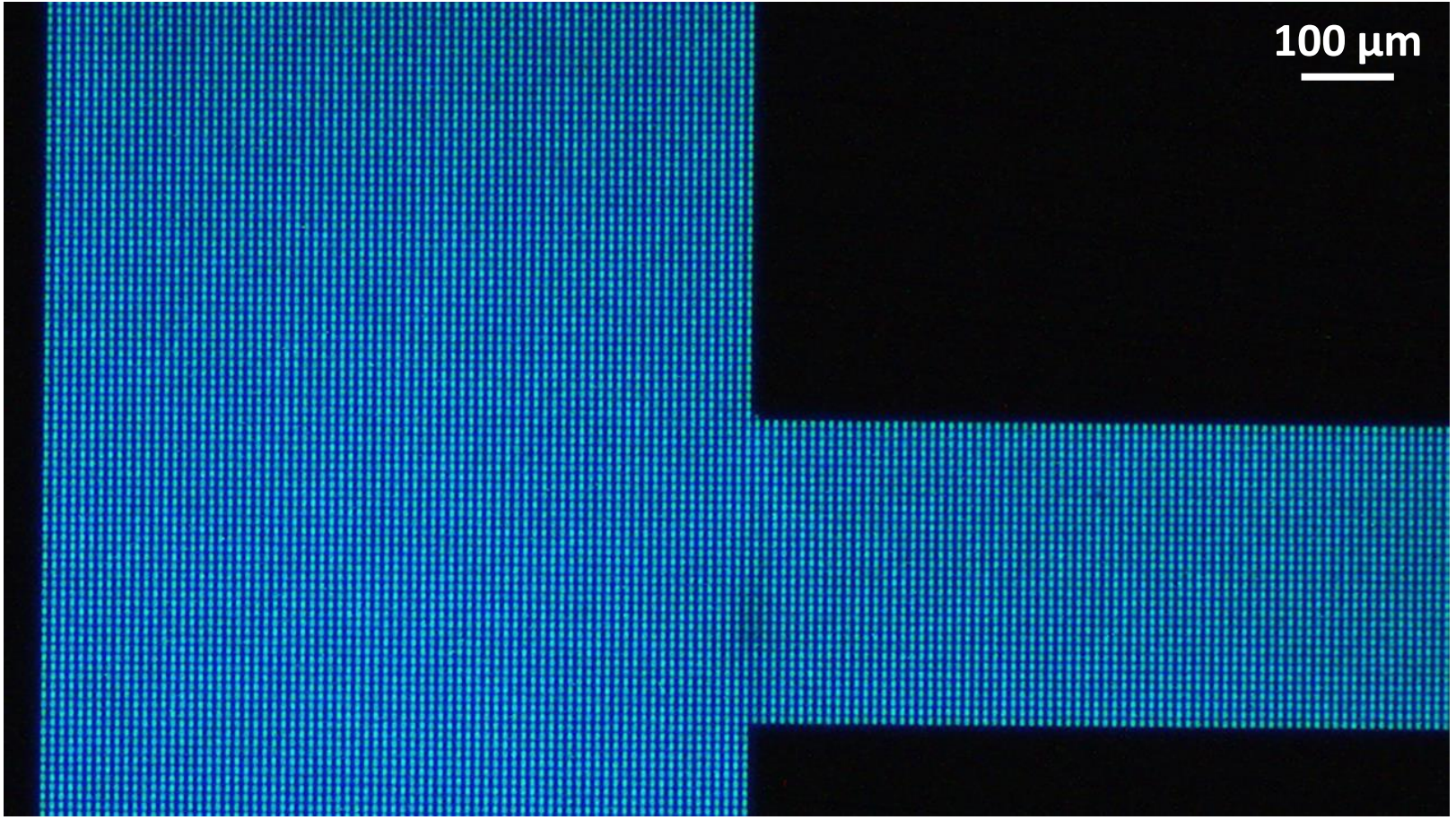
bottom emission



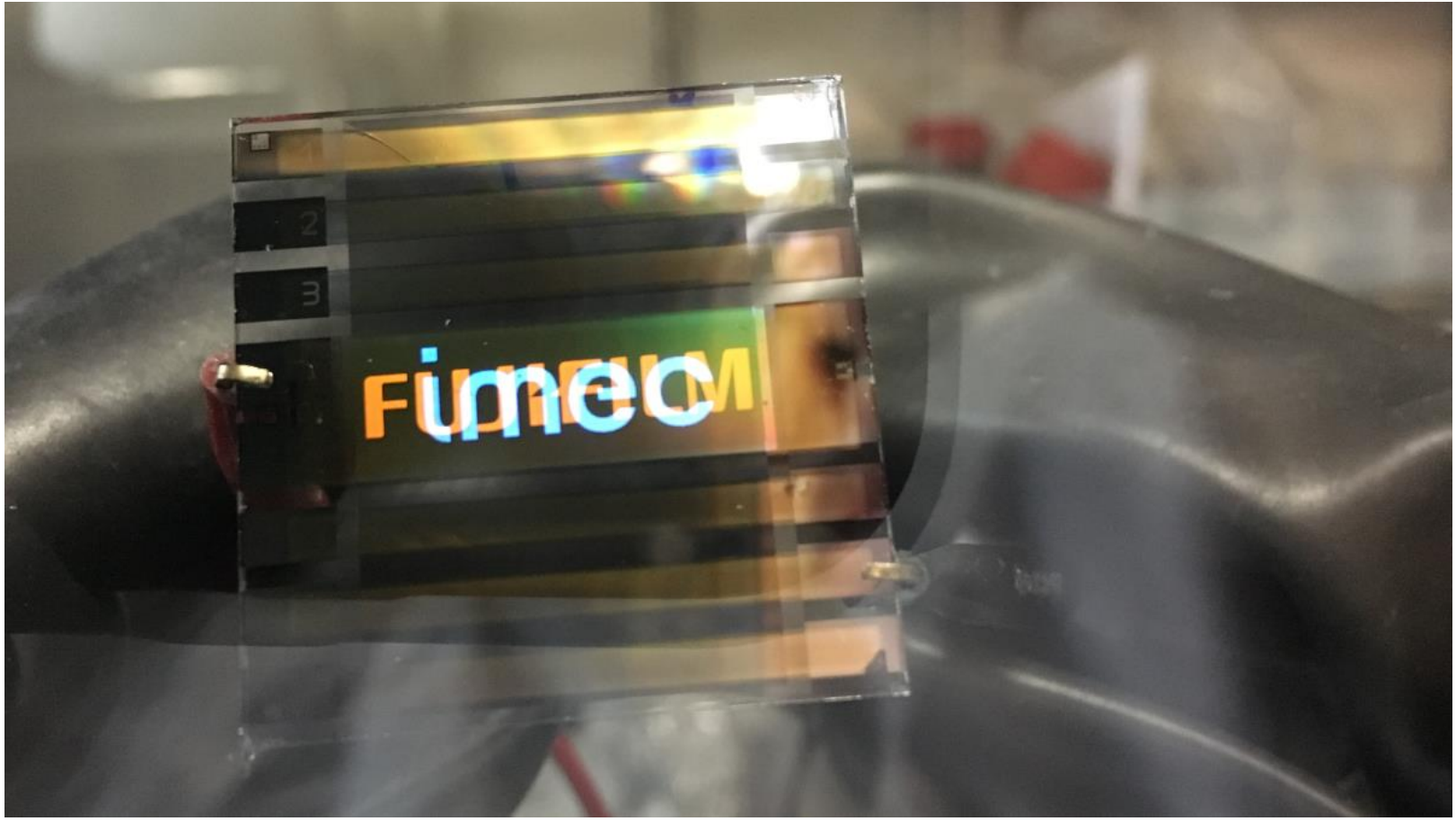
2500 PPI PASSIVE DISPLAY: FLUORESCENT BLUE



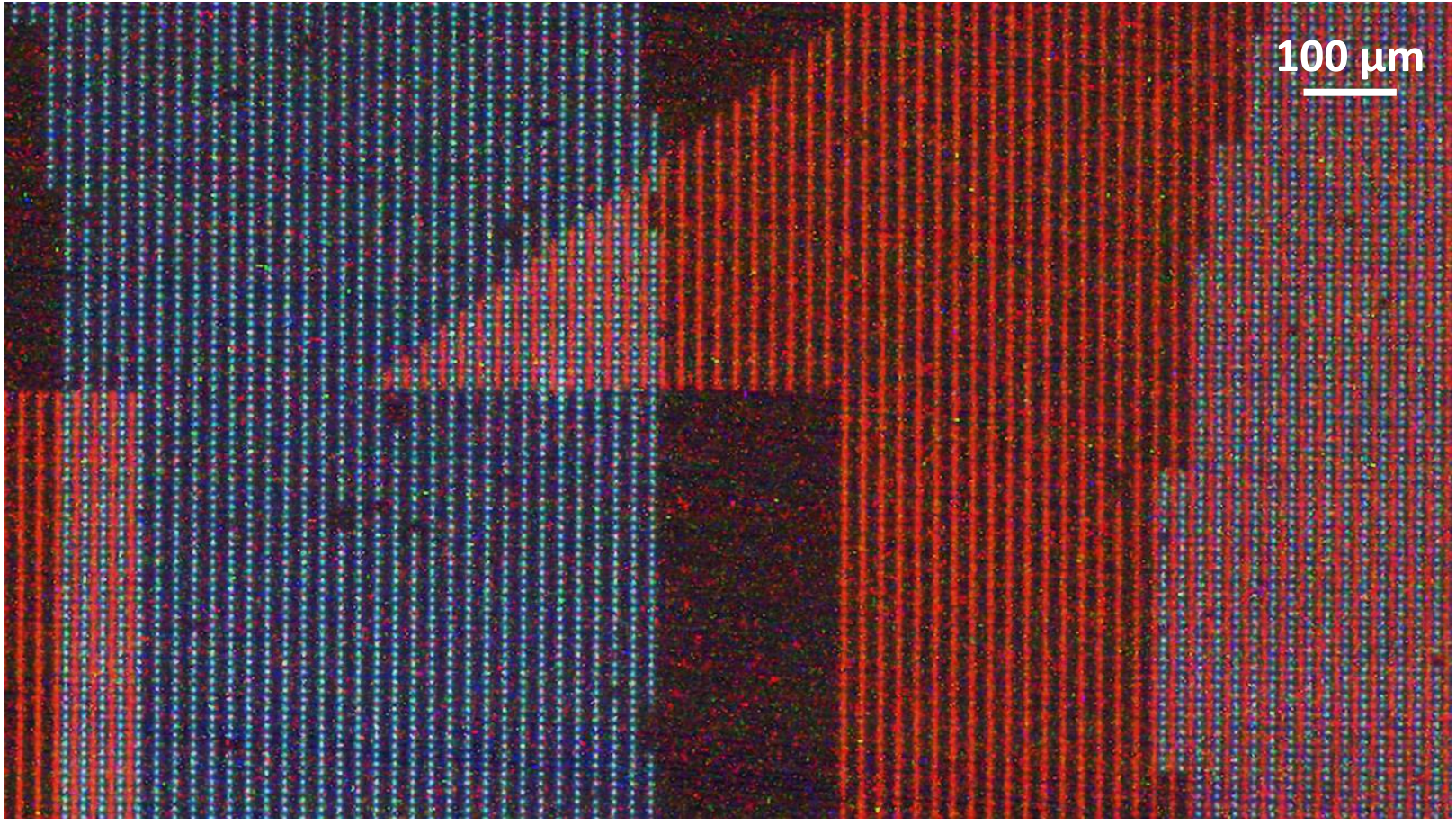
2500 PPI PASSIVE DISPLAY: FLUORESCENT BLUE



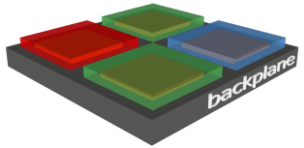
1250 PPI DOUBLE COLOR – ORANGE/BLUE



1250 PPI DOUBLE COLOR – ORANGE/BLUE



SUMMARY



RGB OLED
by photolithography

evaporated OLEDs

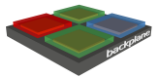
10 µm pixel pitch

2 color patterning

1900x600 pixel array

top emission

NEXT STEPS



RGB OLED
by photolithography

lifetime improvement

1250 ppi RGB arrays

integration on active matrix

INTRODUCTION

INTERNET OF THINGS

IMEC

LARGE AREA ELECTRONICS

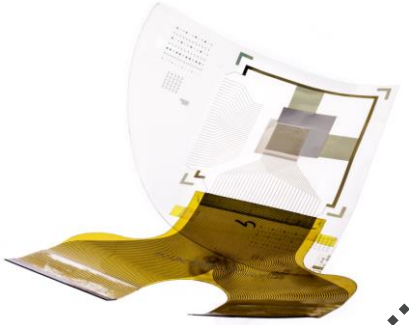
CIRCUITS

DISPLAYS

IMAGE SENSORS

WORKSHOP

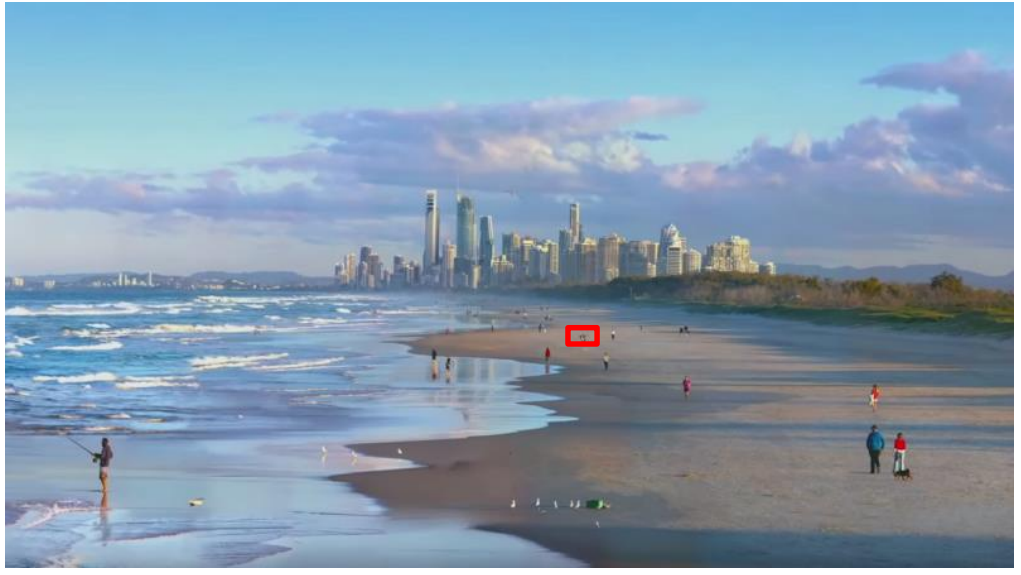
IMAGE SENSOR EVOLUTION



?

CAMERA SPECS: HIGH RESOLUTION

- CAPTURE IN THE DARK
- PRESERVE THE SCENE IN MOTION
- REALIZE RAZOR-SHARP RESOLUTION

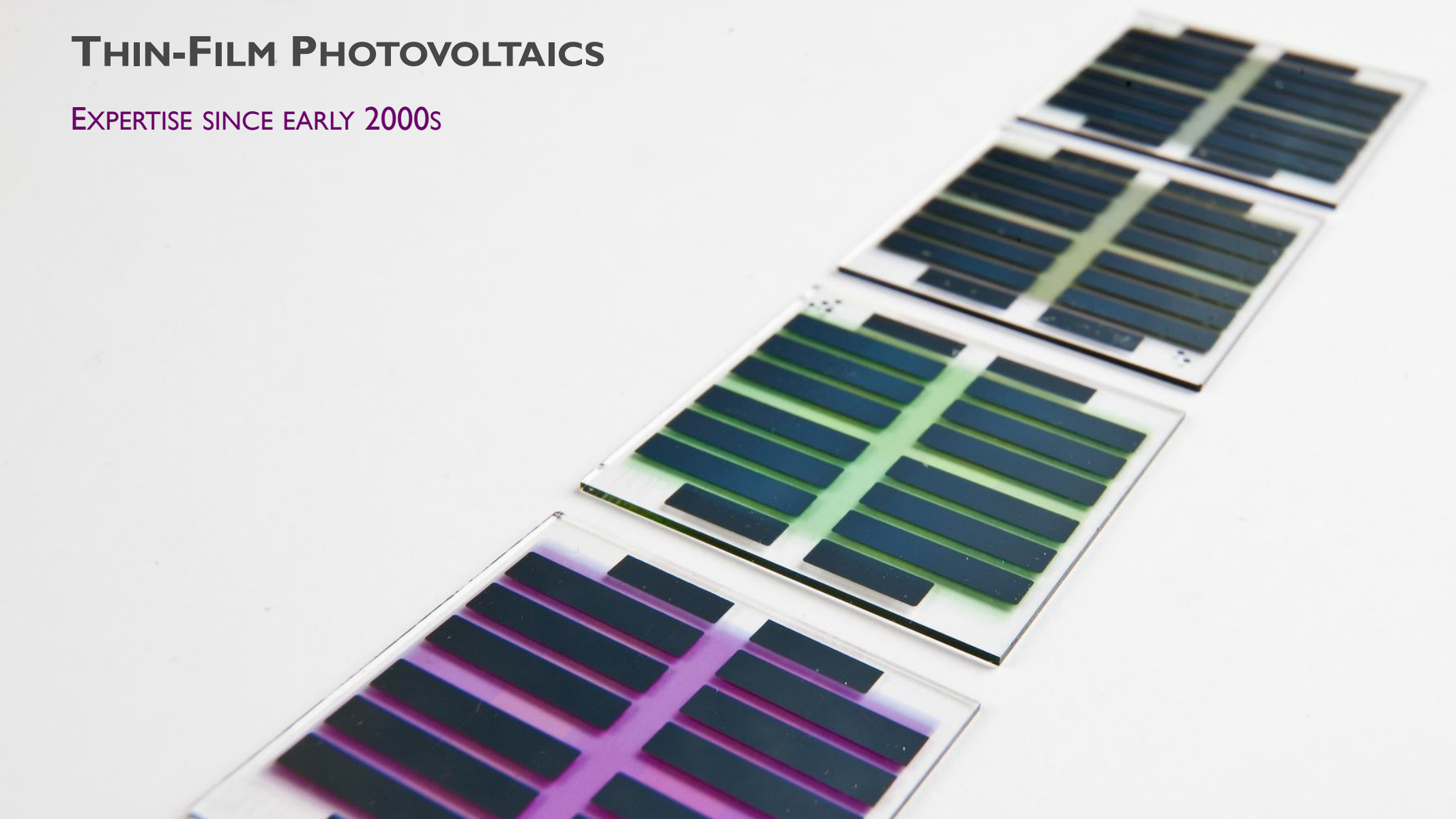


THIN-FILM PHOTODETECTOR

TFPD

Thin-Film Photovoltaics

Expertise since early 2000s



THIN-FILM PHOTODETECTORS

high absorption coefficient
→ ultra-thin active layers

low processing temperature
→ easy integration on anything

(possibly) low cost
→ reusable/disposable

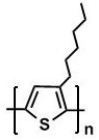
TFPD

tunable spectrum
→ matching wavelength

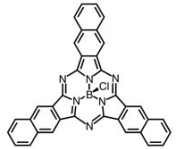
large-area coating
→ high throughput

THIN-FILM PHOTODETECTORS

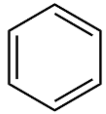
polymers



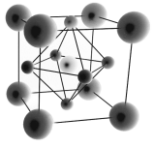
small molecules



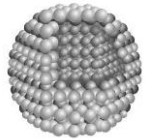
organic (OPD)



TFPD

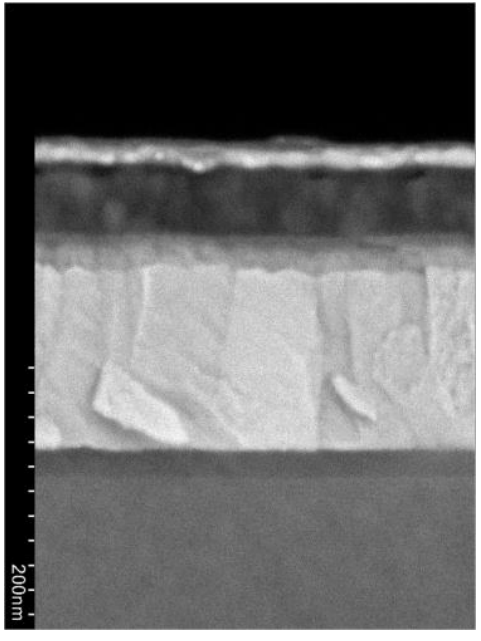


perovskites



quantum dots

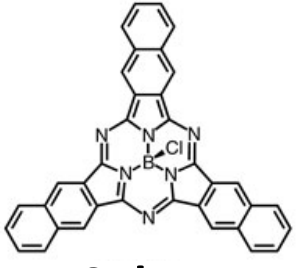
SMALL MOLECULE OPDS: ULTRATHIN ACTIVE LAYER



Ag (15 nm)
BCP (10 nm)
C_{60} (40 nm)
SubPc (10 nm)
MoO_3 (15 nm)
ITO (140 nm)
Glass

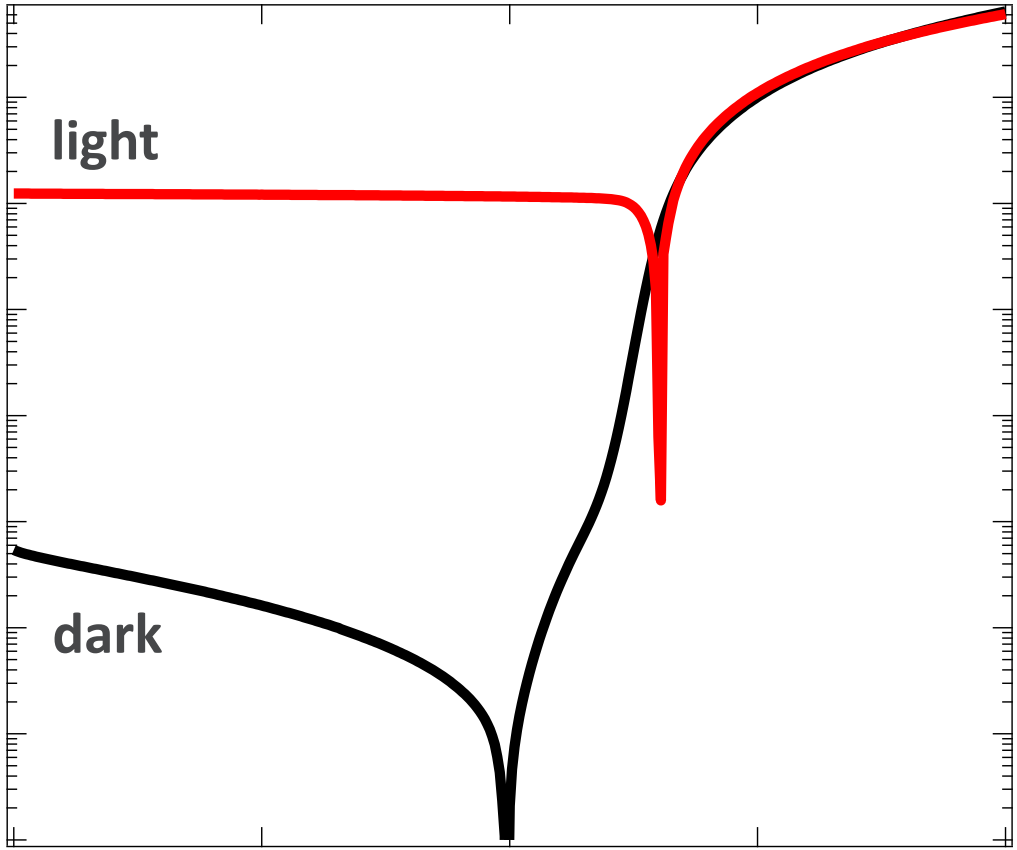
active layer cross-section

C_{60}

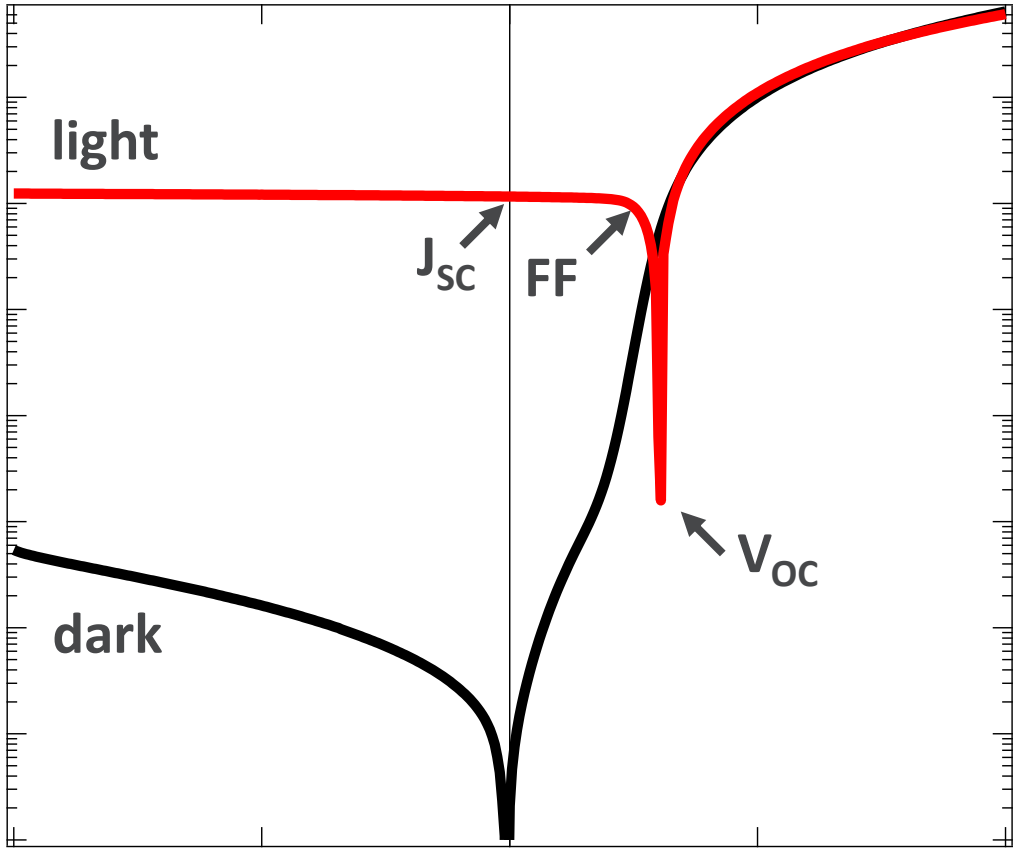


SubPc

OPD VS. OPV: CURRENT-VOLTAGE



OPV: High Efficiency



Measured parameters:

J_{SC}: short-circuit current

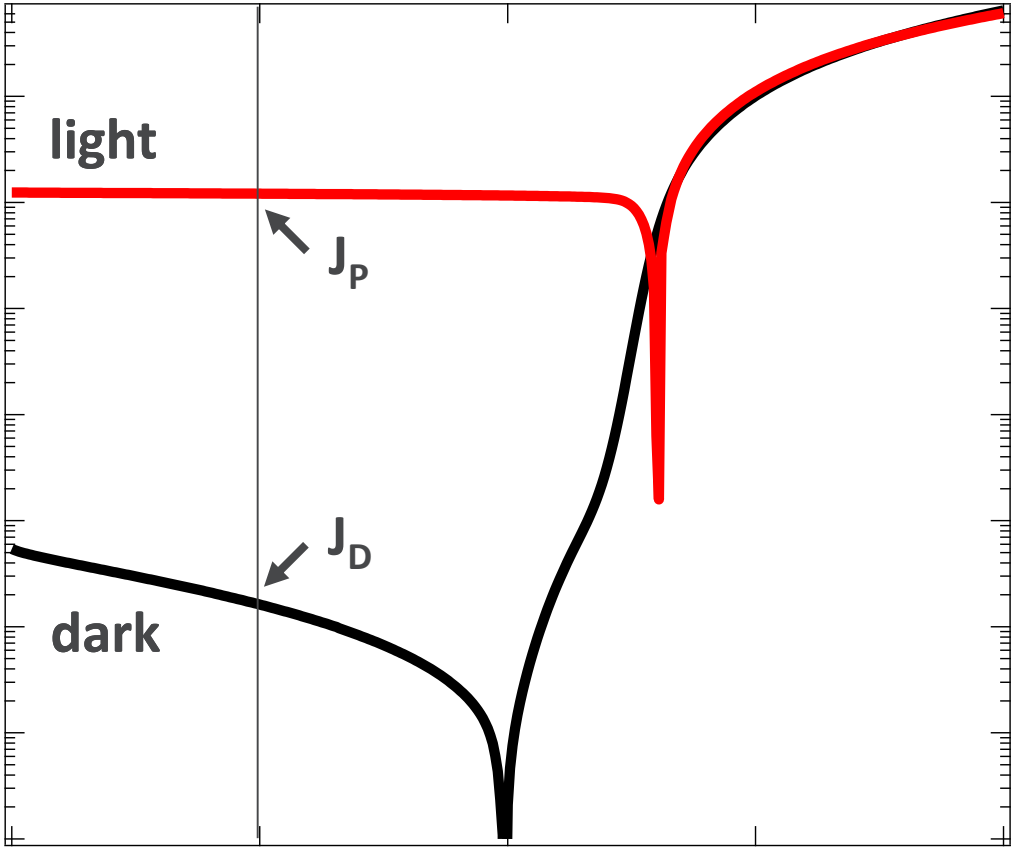
V_{OC}: open-circuit voltage

FF: fill factor

Relevant specs:

η: power conversion efficiency

OPD: High Sensitivity



Measured parameters:

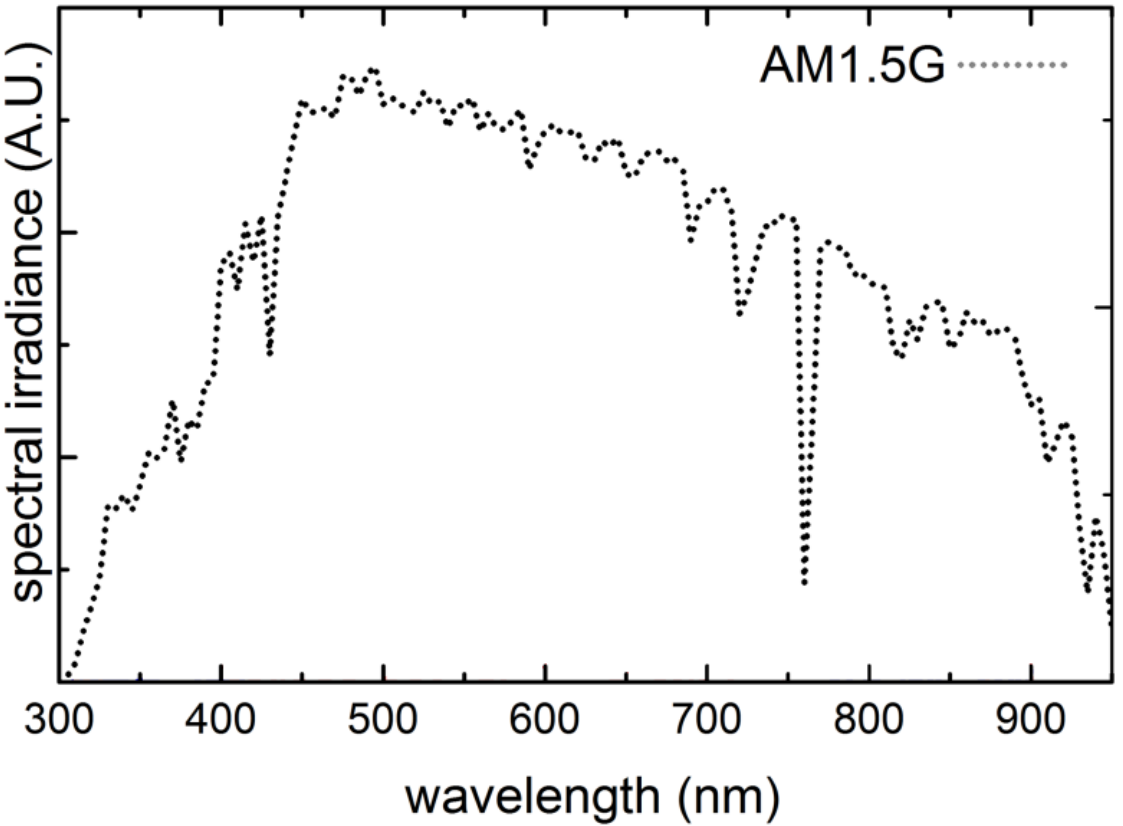
J_D: dark current at given bias

J_P: photocurrent at given bias

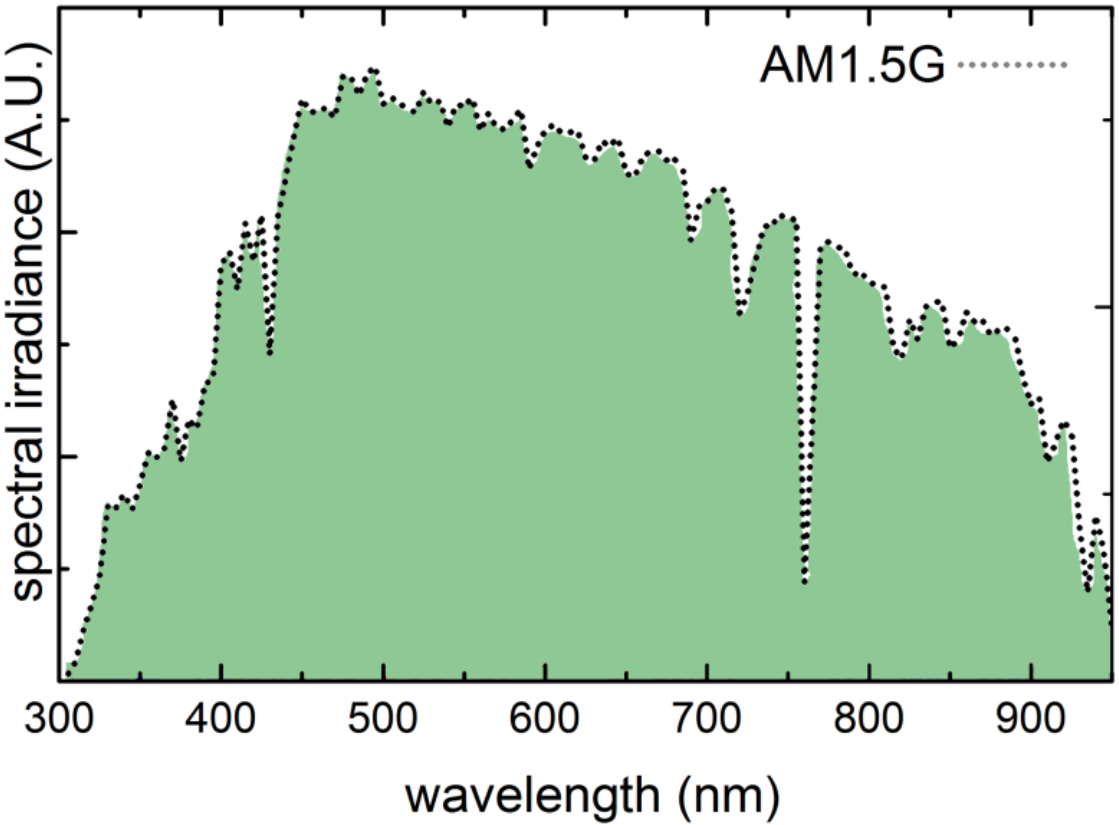
Relevant specs:

SNR: signal-to-noise ratio

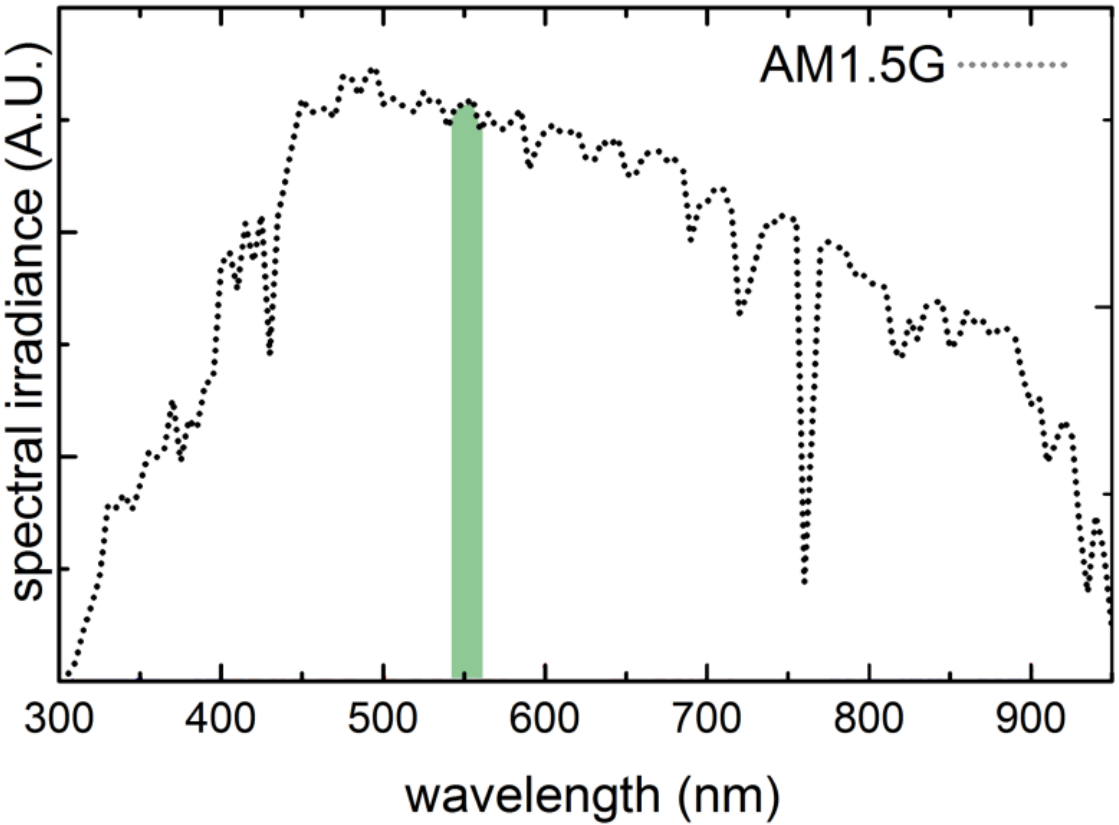
OPD VS. OPV: SPECTRUM



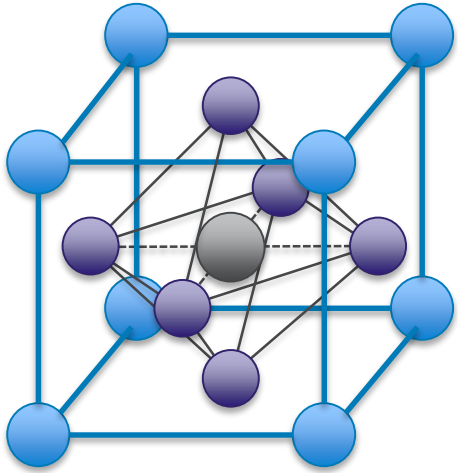
OPV: Wide Coverage



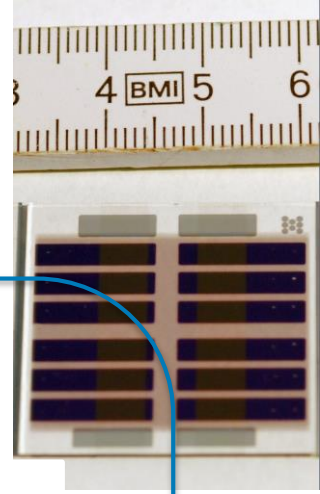
OPD: Specific Lines



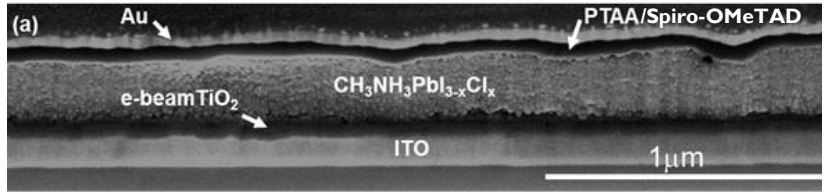
PEROVSKITE PV

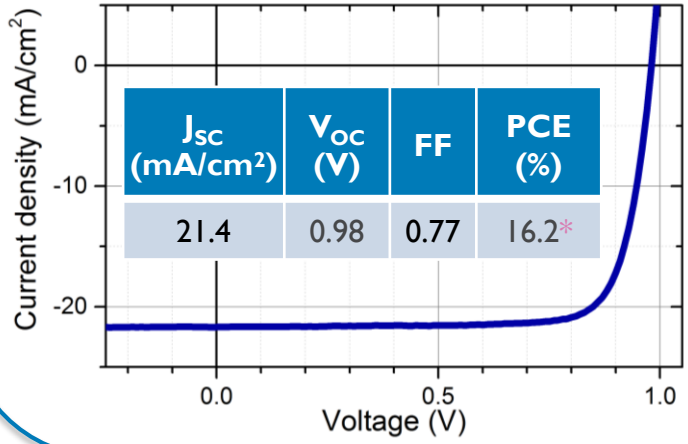


- Large cation (organic, ..
- Small cation (Pb^+)
- Anion (I^-, Br^-,...)

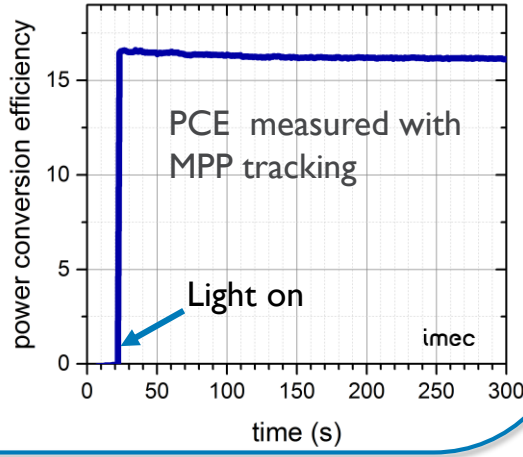


Perovskite Top Solar Cell:



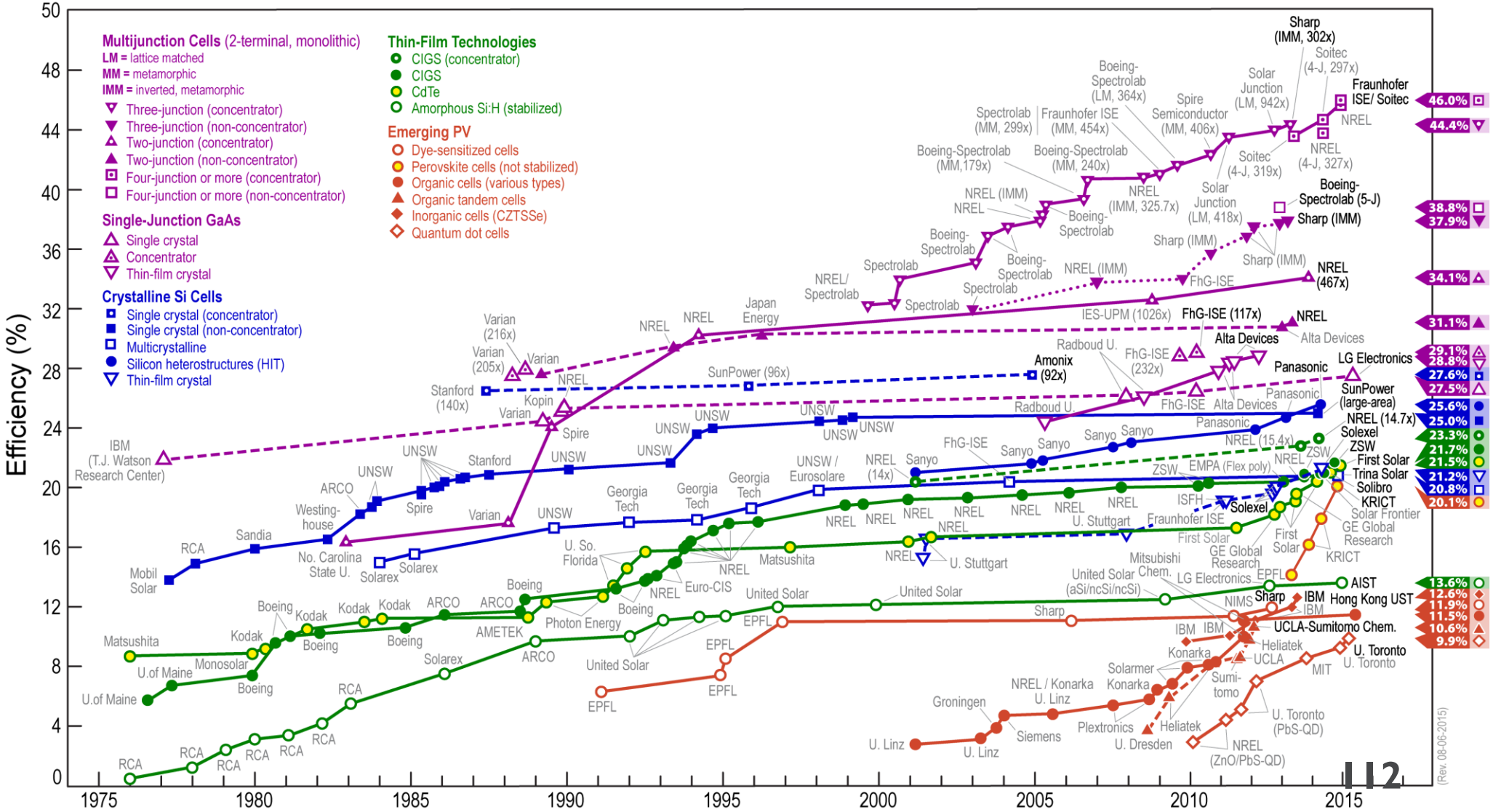


J_{SC} (mA/cm²)	V_{OC} (V)	FF	PCE (%)
21.4	0.98	0.77	16.2*



*Best 17%

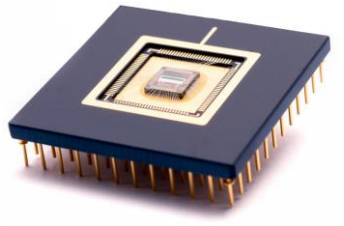
Best Research-Cell Efficiencies



THIN-FILM PHOTODETECTOR ARRAYS: INTEGRATION

- ***TFPD***
  - ***on TFT***

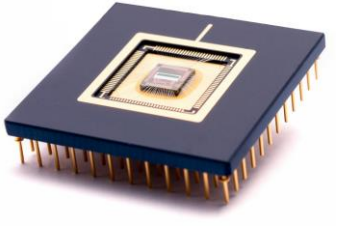
  - ***on CMOS***



THIN-FILM IMAGE SENSORS

- *TFPD*
  - *on TFT*

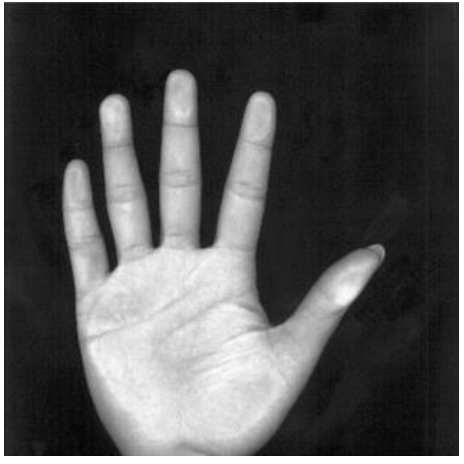
    - *non-destructive testing*
    - *gesture recognition*
    - *biometric*
    - *x-ray*
      - *indirect*
      - *direct*
  - *on CMOS*



    - *plain / monochrome*
    - *pixelated / multicolor*

BIOMETRICS: LARGE AREA, FLEXIBILITY, HIGH RESOLUTION

large area



palm identification
+ vein pattern (NIR needed)

Lin et al., Sensors, 15 (2015)

conformable

wrap-around sensors

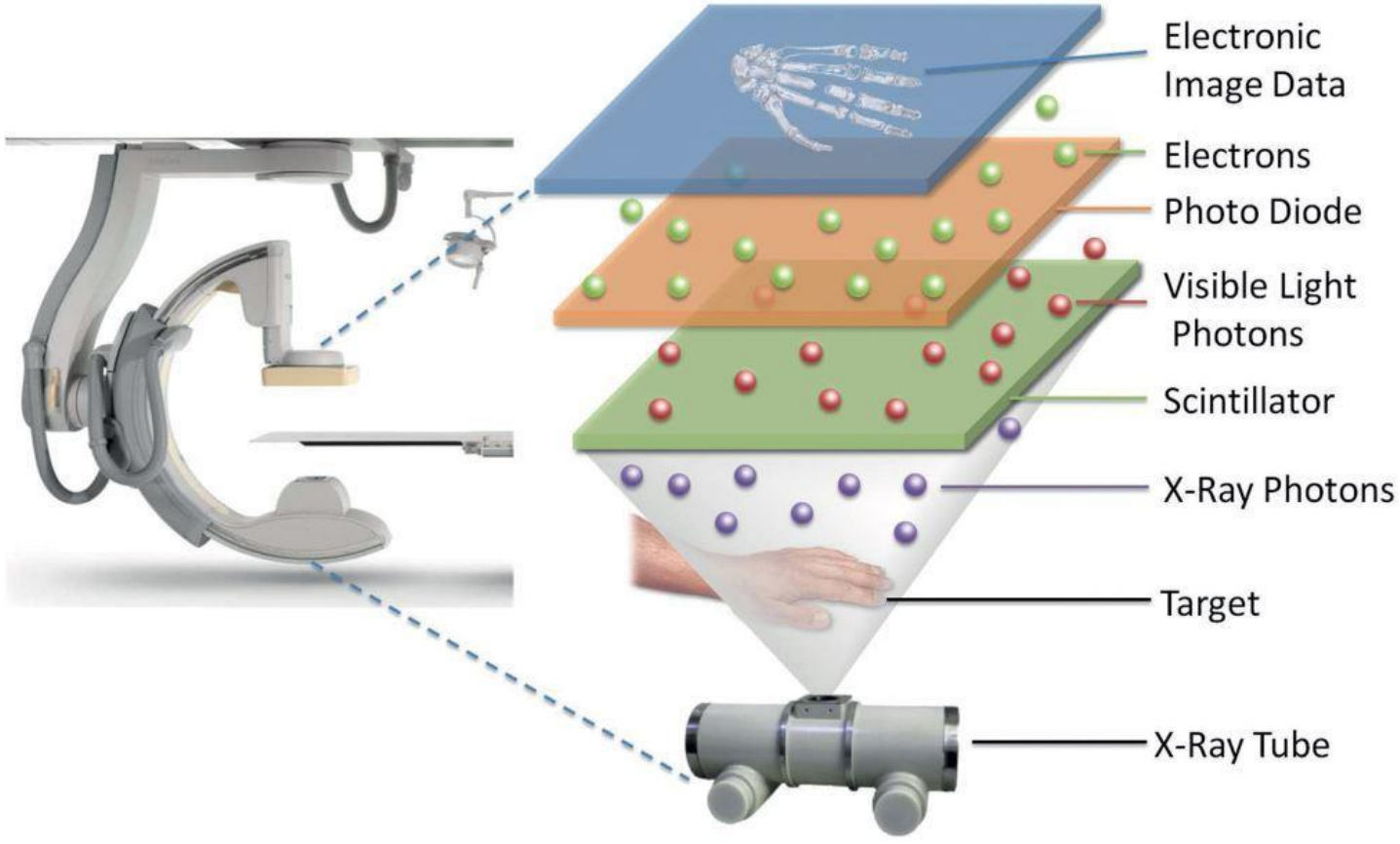
high resolution

FBI fingerprint standards:
Level 2: 500 ppi (50 µm pixel)
Level 3: 1000 ppi (25 µm pixel)
imec IGZO TFT: 30 µm pixel feasible

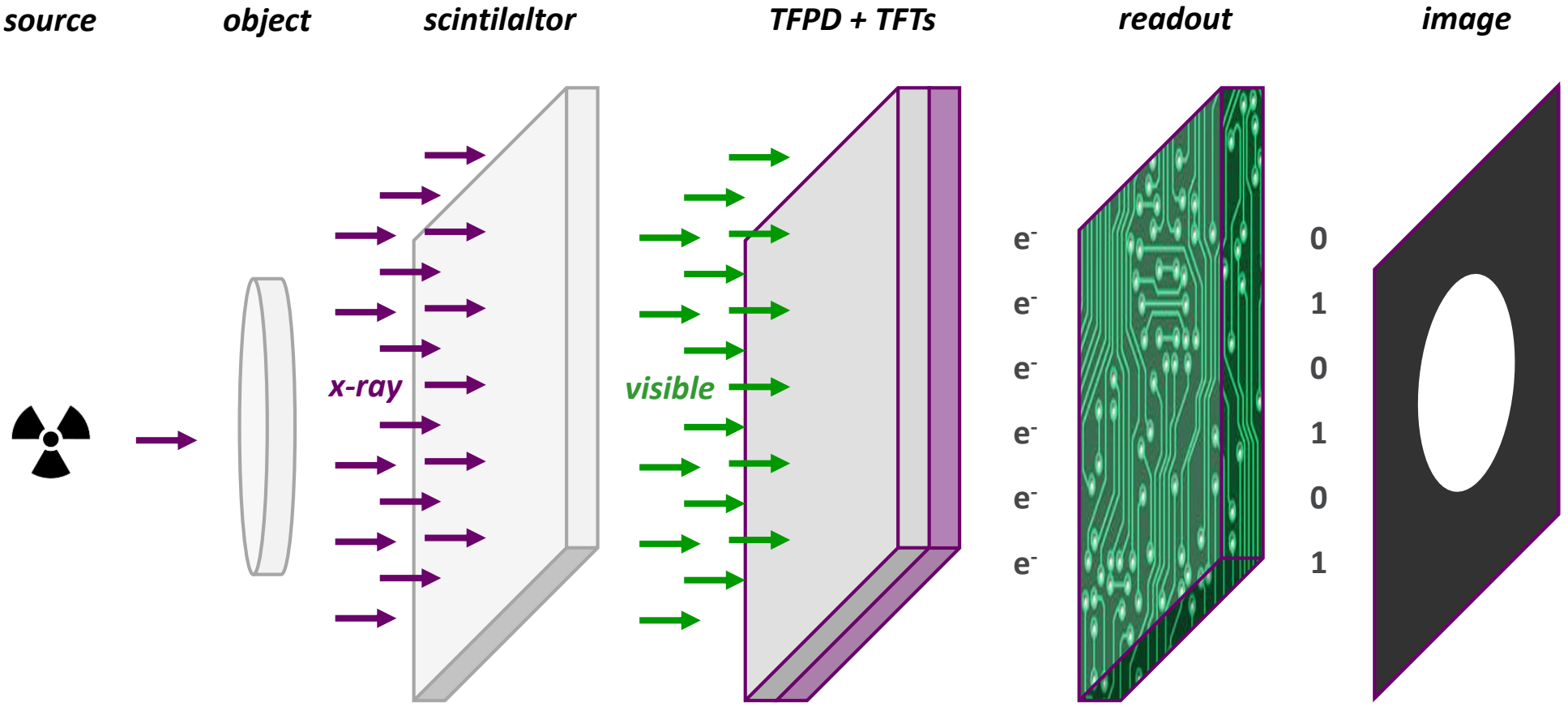
Zwipe/MasterCard, www.zwipe.no

Large Area: X-Ray

INDIRECT X-RAY WITH SCINTILLATOR



X-RAY IMAGING: INDIRECT CONVERSION



X-RAY IMAGE SENSORS: FLEXIBILITY

- plastic substrate processed on glass carrier
  - imager flexible after delamination

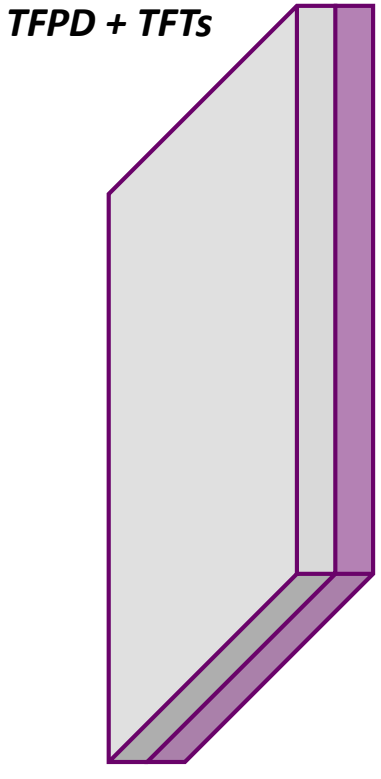
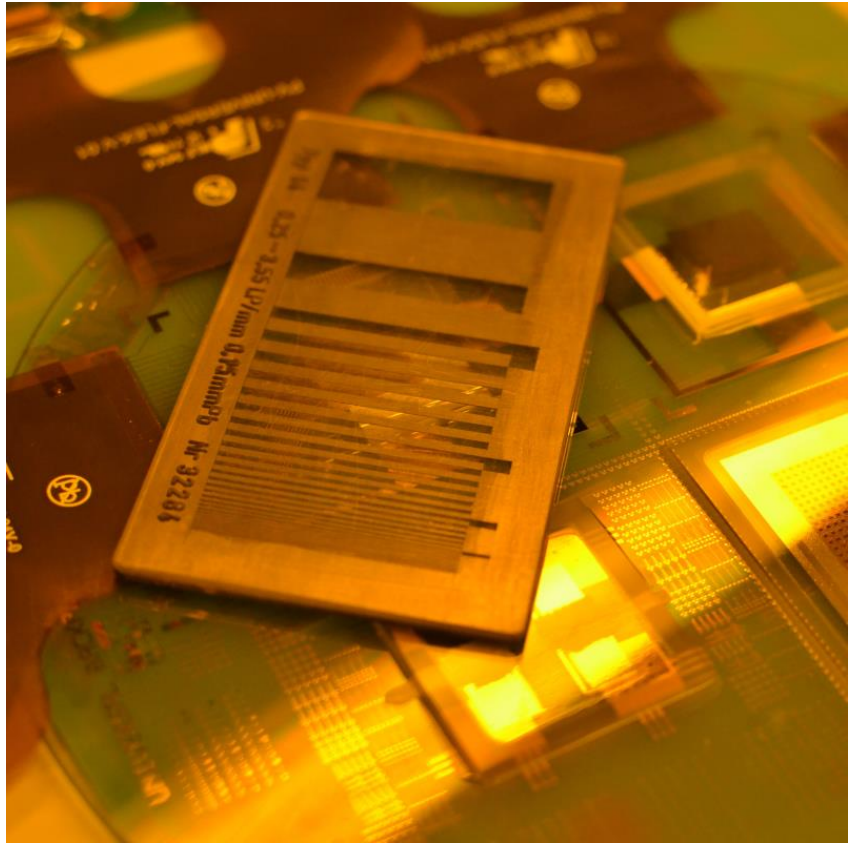


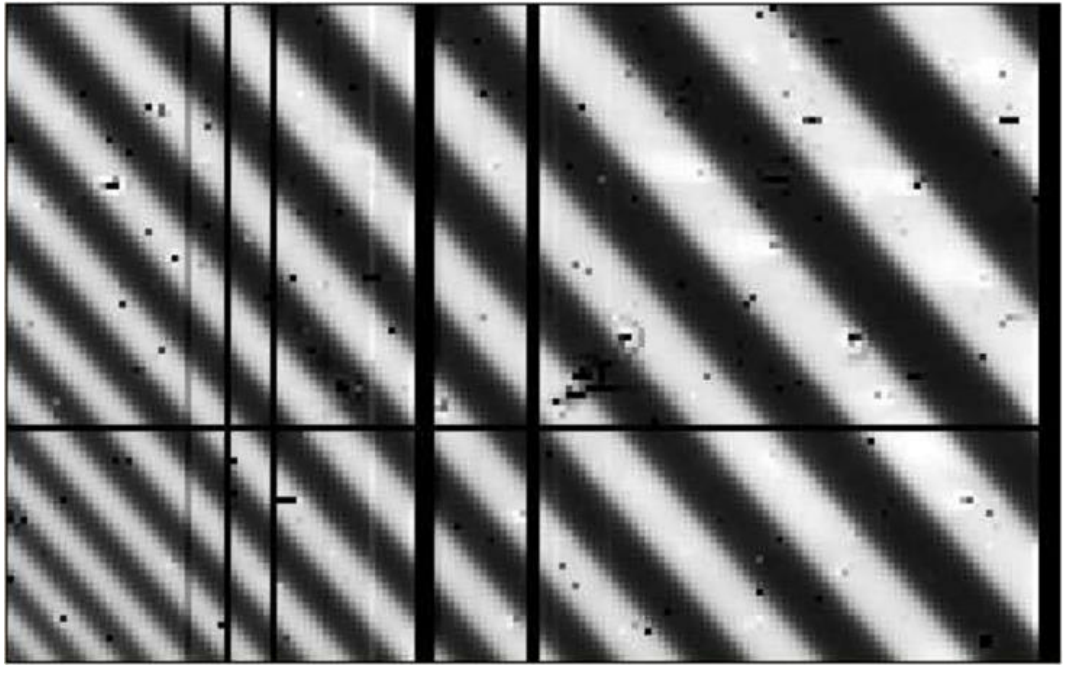
image sensor after delamination

X-RAY IMAGING



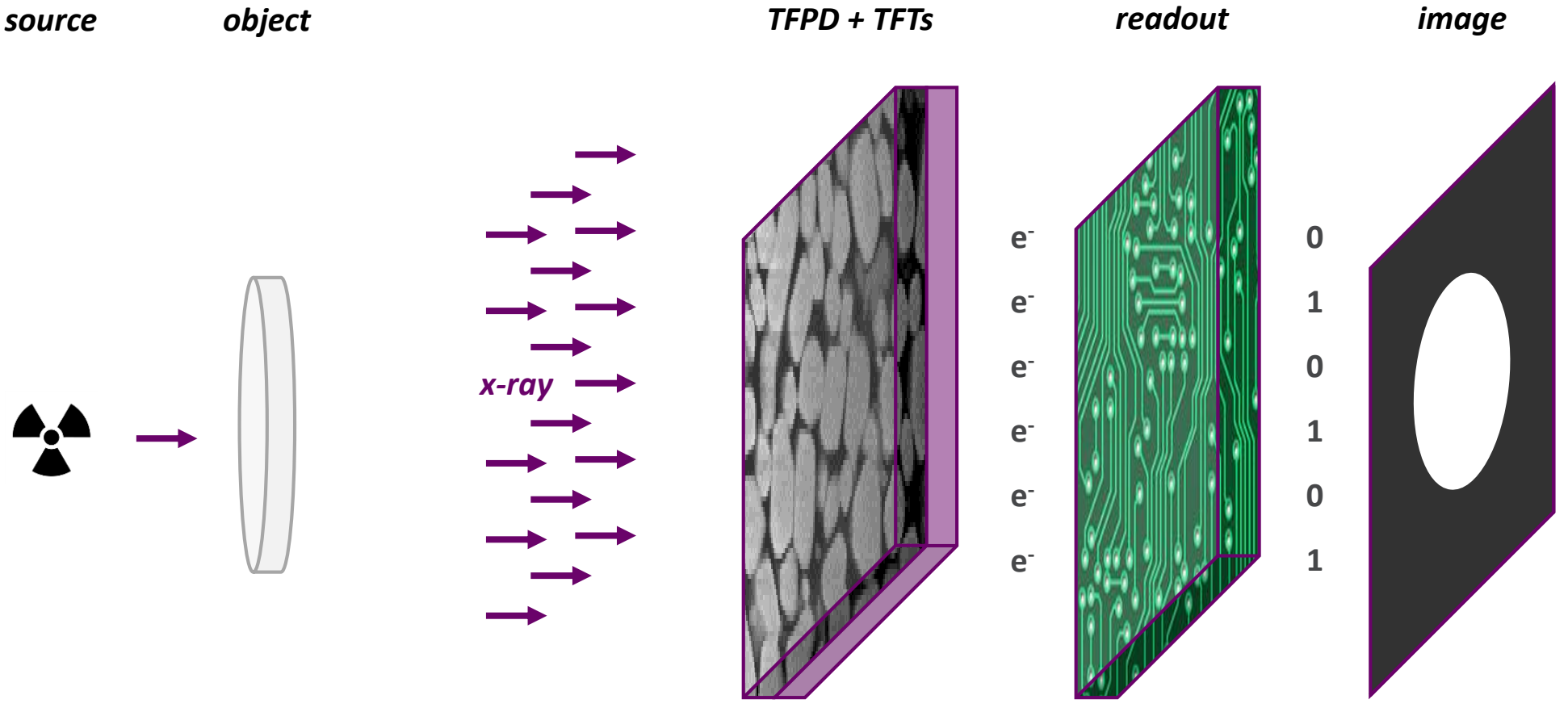
X-RAY IMAGE SENSORS: IMAGING

- imaging with scintillator and metal grid



x-ray shadow image

X-RAY IMAGING: DIRECT CONVERSION



DiCoMo: European Consortium

- Horizon 2020 project DiCoMo
  - partners: Siemens (DE), BASF (CH), imec (BE), TNO (NL), IC Sense (BE), Morphwize (IT)
  - duration: 01.01.2015 to 31.12.2017

SIEMENS

BASF
We create chemistry

imec

TNO innovation for life

ICsense
THE IC DESIGN COMPANY

morphwize
generative & specialty simulators
for science and business

THIN-FILM PHOTODETECTORS

ultra-thin active layers
→ very low cross-talk
→ slanted rays capture

easy integration on anything
→ moving photodiode away from Si

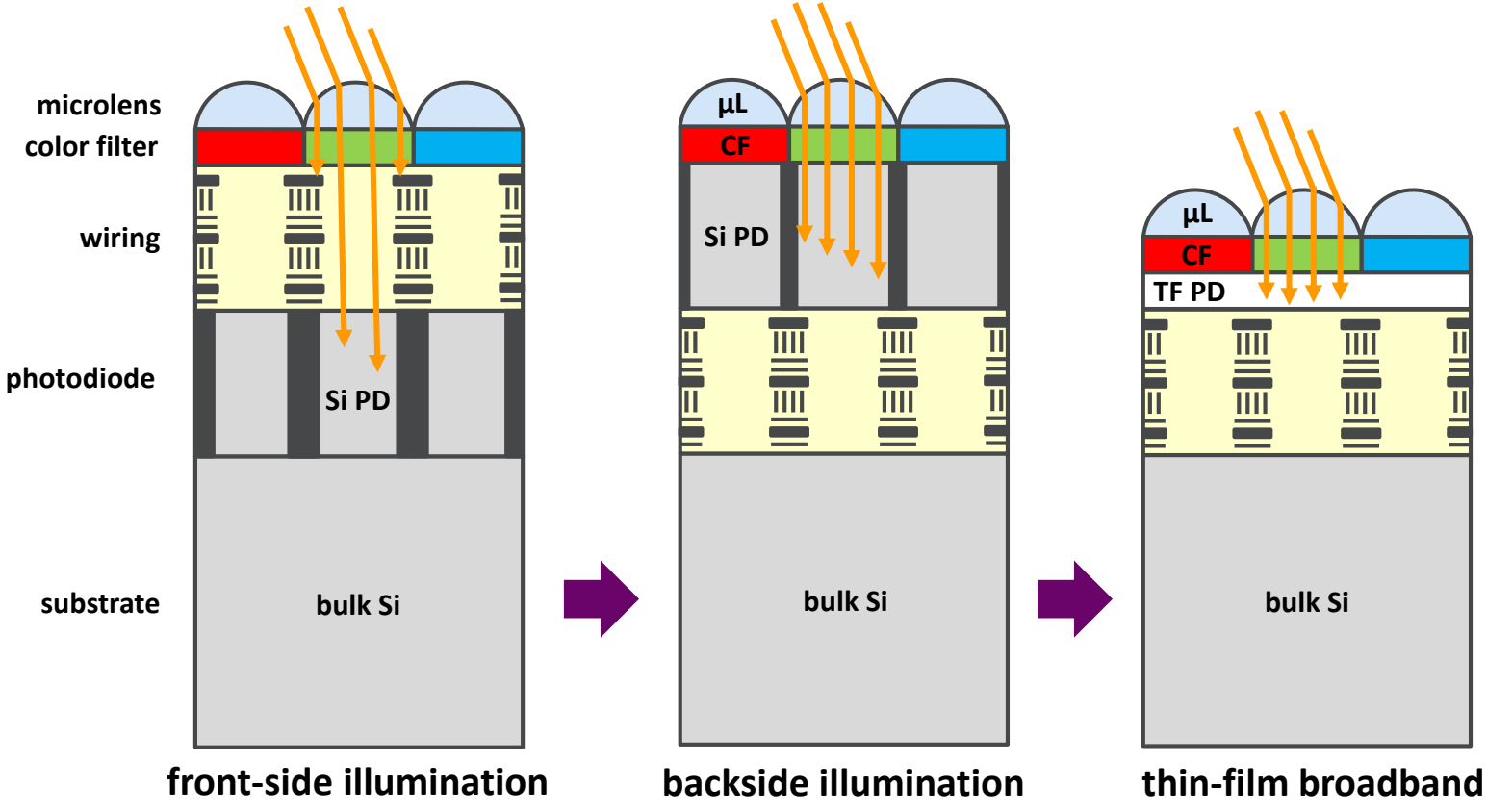
(possibly) low cost
→ monolithic (not hybrid)

TFPD on CMOS

tunable spectrum
→ near infrared extension

large-area coating
→ high throughput

CMOS IMAGER TECHNOLOGIES: THIN-FILM

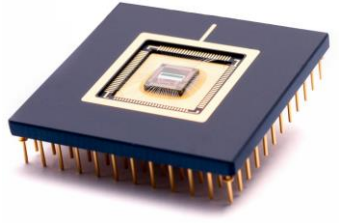


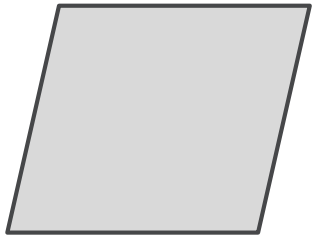
THIN-FILM IMAGE SENSORS

TFPD

on TFT

on CMOS



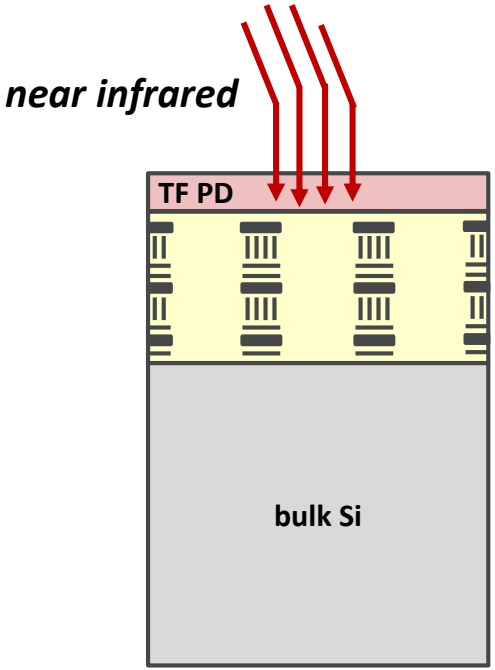


plain / monochrome

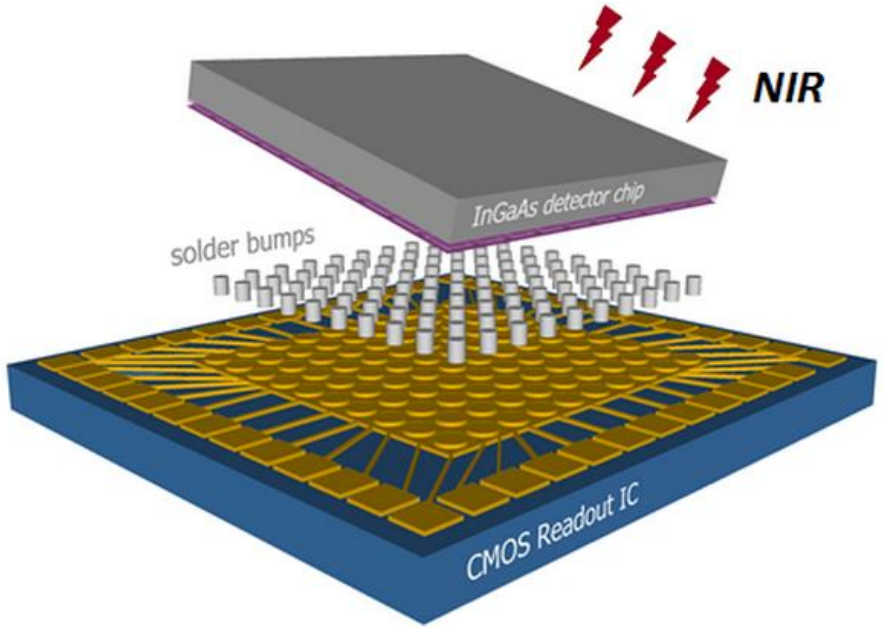
pixelated / multicolor

CMOS IMAGER TECHNOLOGIES: THIN-FILM

- replacing flip-chip bonded III-V hybrid by a monolithic configuration

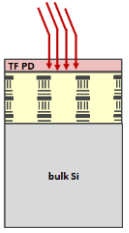


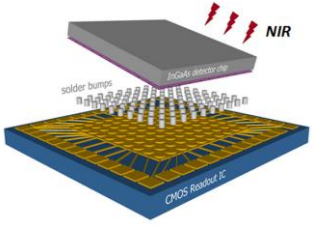
monolithic thin-film



hybrid III-V flip-chip

CMOS IMAGER TECHNOLOGIES: THIN-FILM





monolithic thin-film

pixel pitch < 1 µm
→ *enabled by advanced CMOS*

thin-film active layer
→ *easily upscalable to 300 mm wafers*
→ *VIS/NIR feasible in the same focal plane*

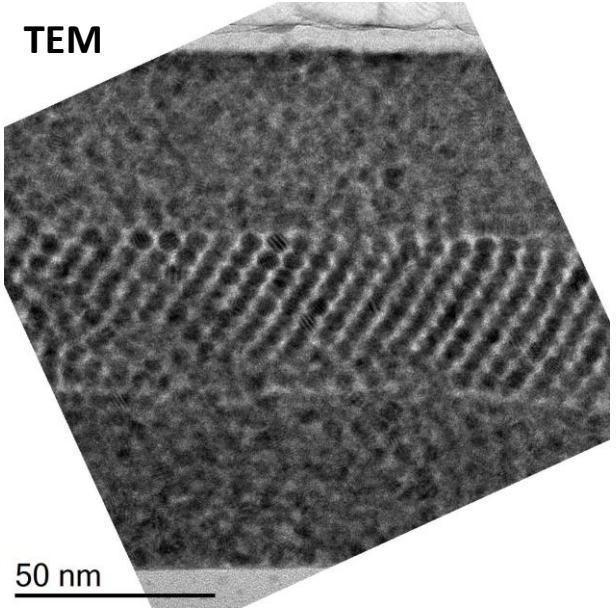
hybrid III-V flip-chip

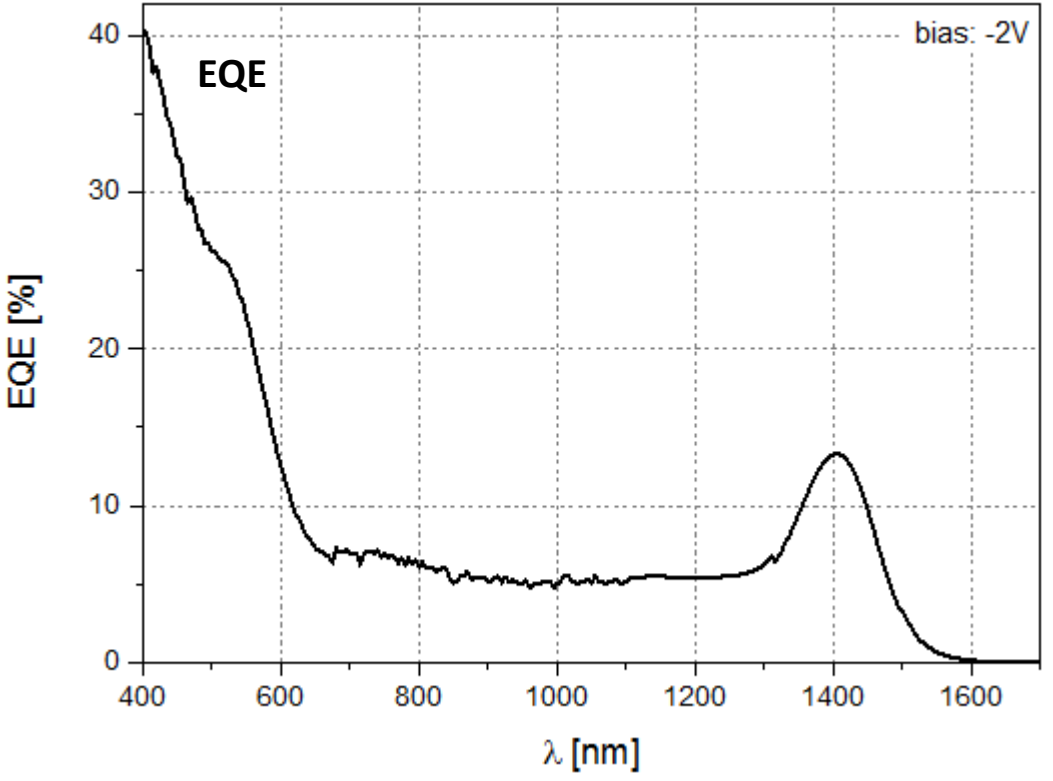
pixel pitch > 10 µm
→ *limited by flip-chip*

III-V active layer
→ *expensive epi, wafer size 4 inch*
→ *only infrared for the same focal plane*

QD Photodetector for Infrared

- quantum dot photoactive layer with absorption in the infrared range
- EQE above 10% at 1.4 µm wavelength from a 150 nm thin layer



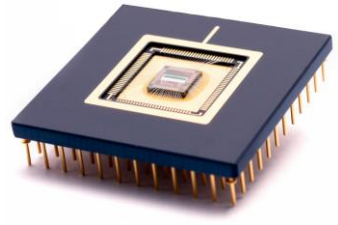


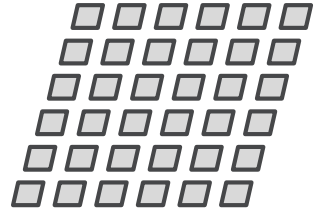
THIN-FILM IMAGE SENSORS

TFPD

on flex

on CMOS

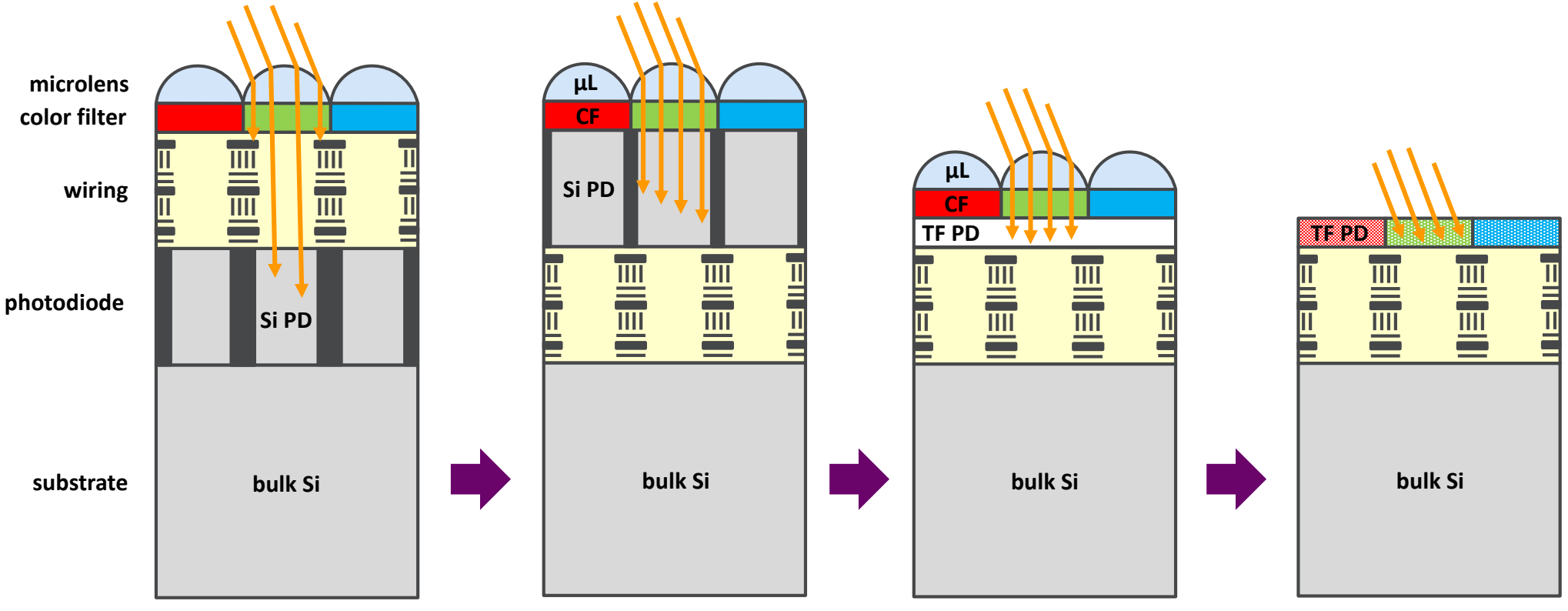




plain / monochrome

pixelated / multicolor

CMOS IMAGER TECHNOLOGIES: THIN-FILM RGB

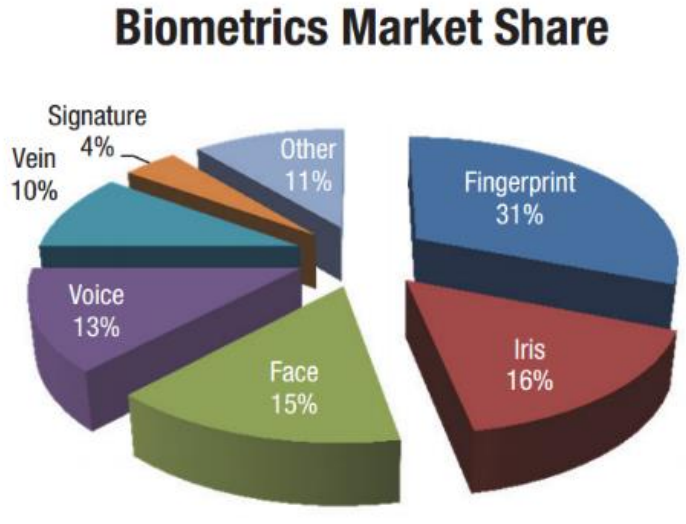


EXISTING MARKET

x-ray imager: 10 B€ in 2016

fingerprint sensor: 14.5 B€ by 2020

existing market



PALM SENSOR

conformable palm scanner for biometric identification

yesterday

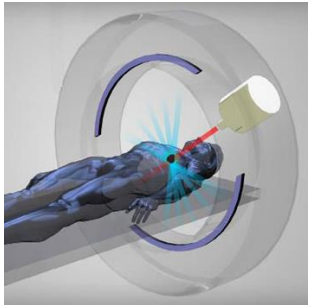
today: flat panel

tomorrow: conformable

MARKET OPPORTUNITIES

market

new



3D phantom

smart floor

grip ID

tube inspection

iHandle

imaging surface

optical board

smart bandage

SUMMARY

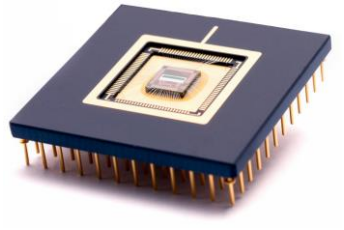
TFPD: AN ENABLER FOR NEW APPLICATIONS

TFPD

on TFT

- *ultra-thin active layers*
- *reusable/disposable*
- *tunable wavelength spectrum*
- *easy integration on any substrate*
- *large-area coating*

on CMOS

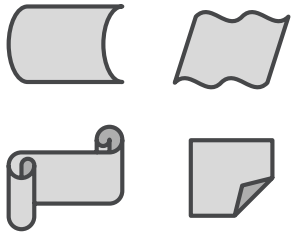


- *moving photodiode away from Si*
- *very low cross-talk*
- *slanted rays capture*
- *monolithic (not hybrid)*
- *extension to near infrared*

SUMMARY

NEW FORM FACTORS AND CONFIGURATIONS

- ***TFPD***
  - ***on TFT***



  - ***on CMOS***