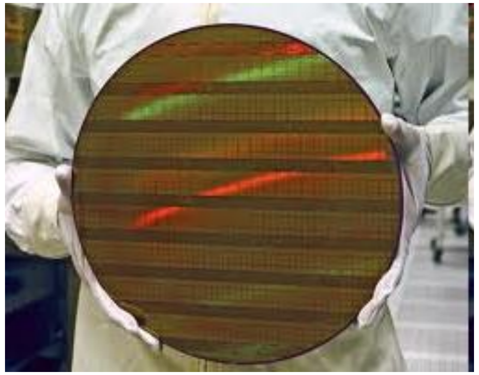
Large Area Electronic Materials

PV-lab
IEM NEUCHATEL

Micro vs. Macro

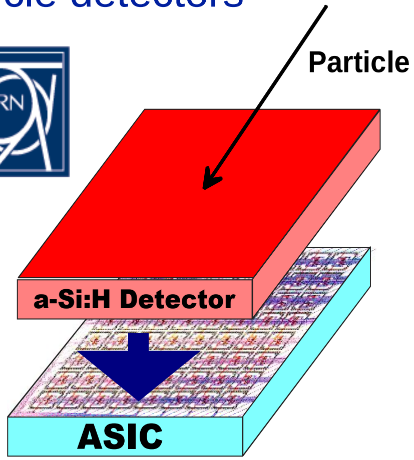
Microelectronics: e.g. NVIDIA GB202:
5 nm lithography TMSC
92 B Transistors on 750 mm^2 die

600 cm^2 wafer (12")

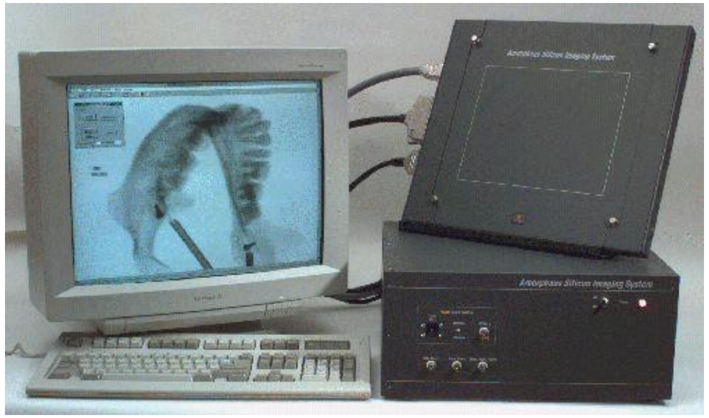


Macroelectronics:
e.g TFT displays
Sharp 8M-B120C (120")
4.01 m^2 (2.6 m x1.5 m)
33 Mio pix (76080x4320)

Particle detectors

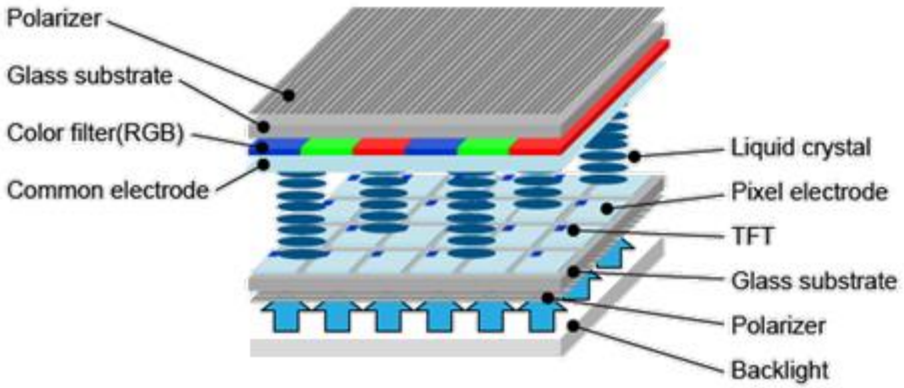


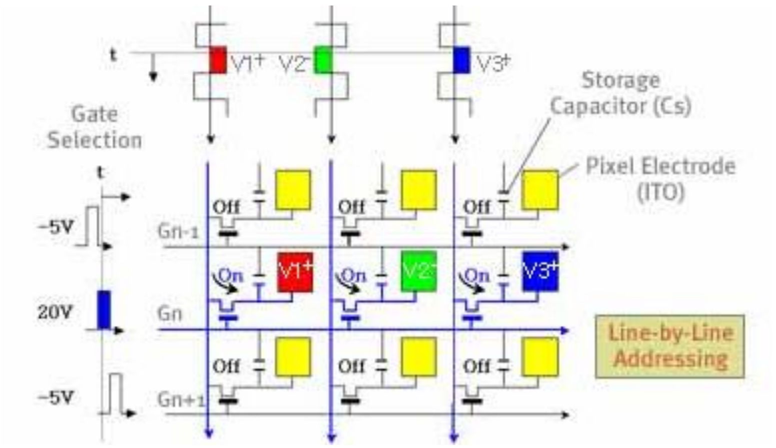
x-ray imagers



What's inside?

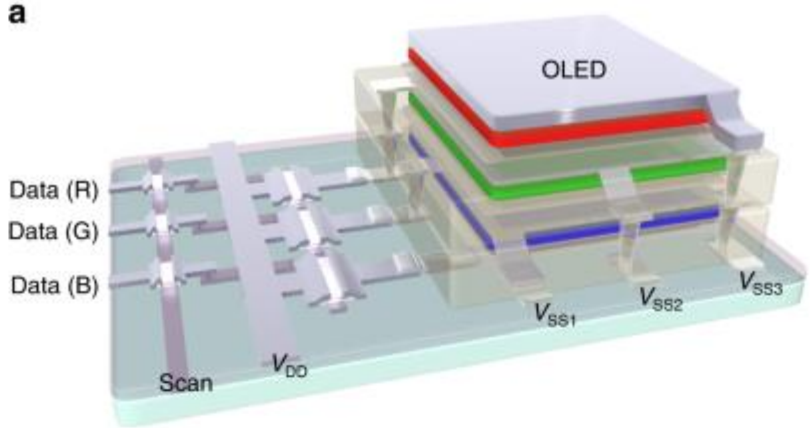
Liquid crystal display (LCD)

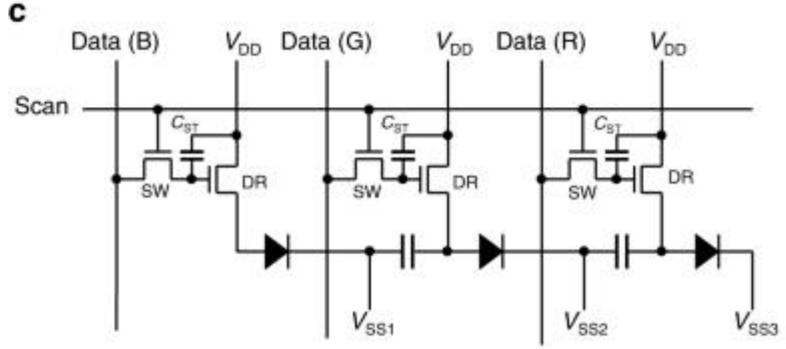




source: j-display.com / rose-hulman.edu

Organic light emitting diode (OLED)

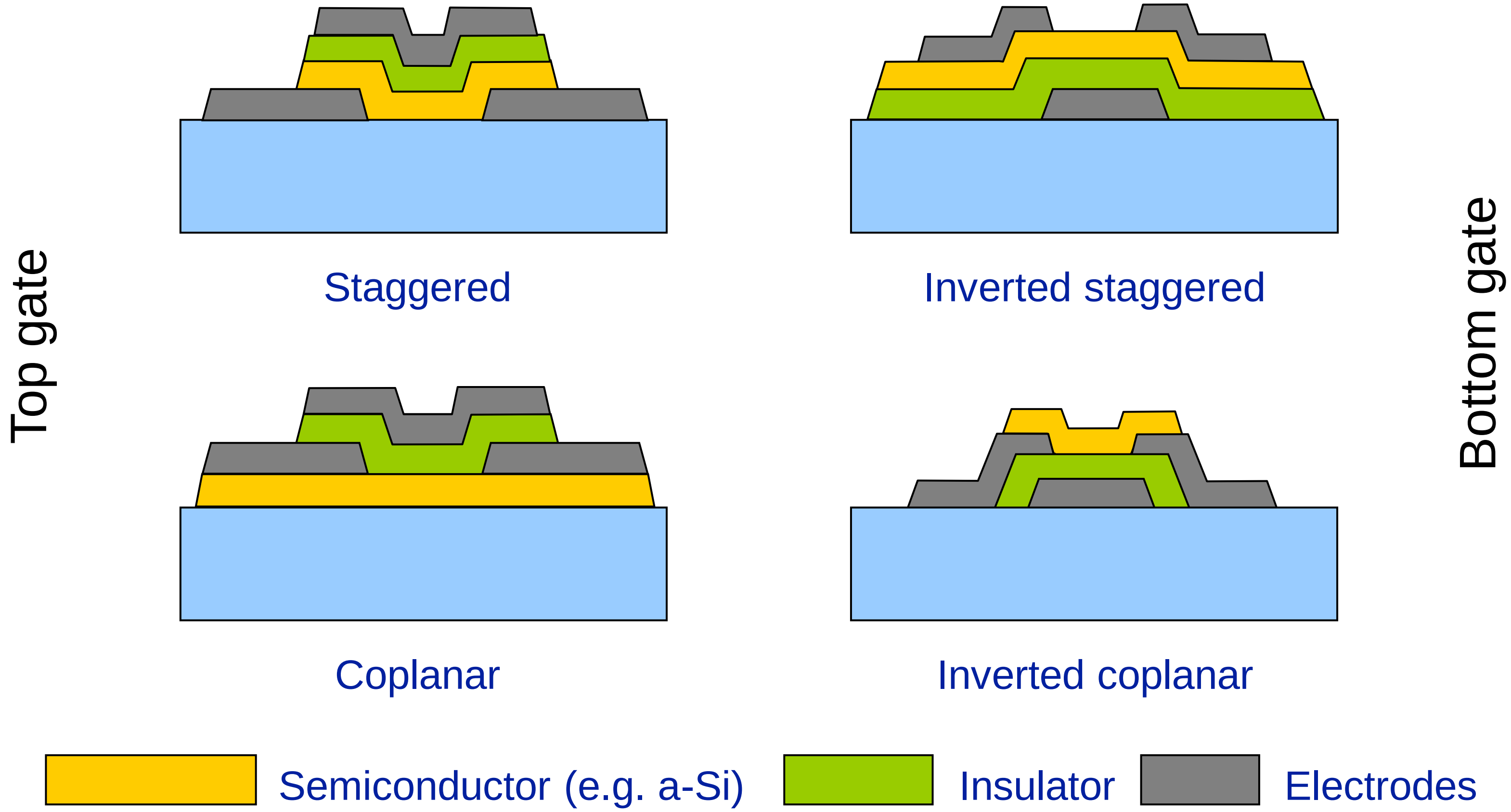




source: Choi, Nature communications 11 (2020)

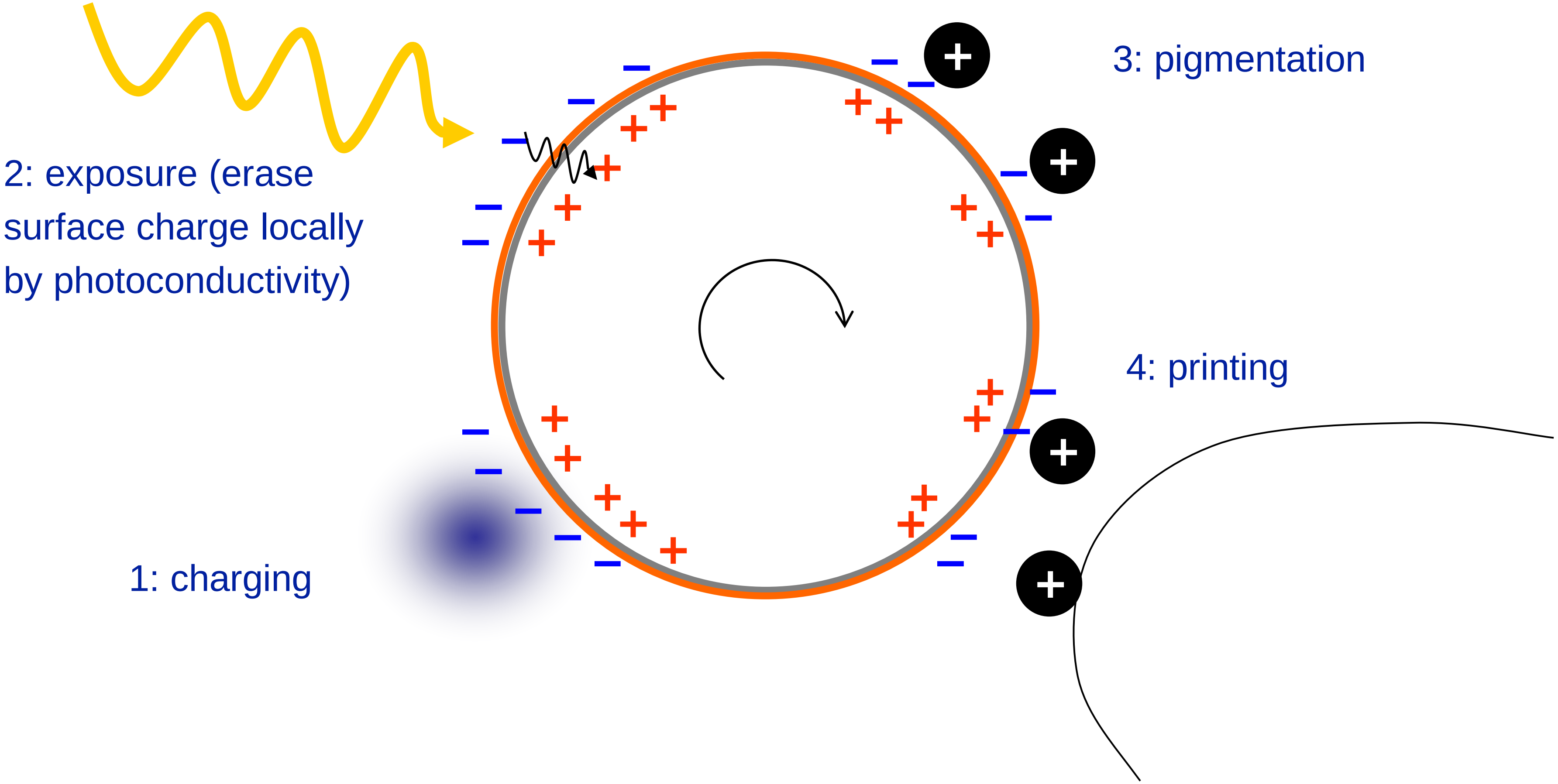
What's inside?

TFT displays: thin film transistor, switch on/off each pixel



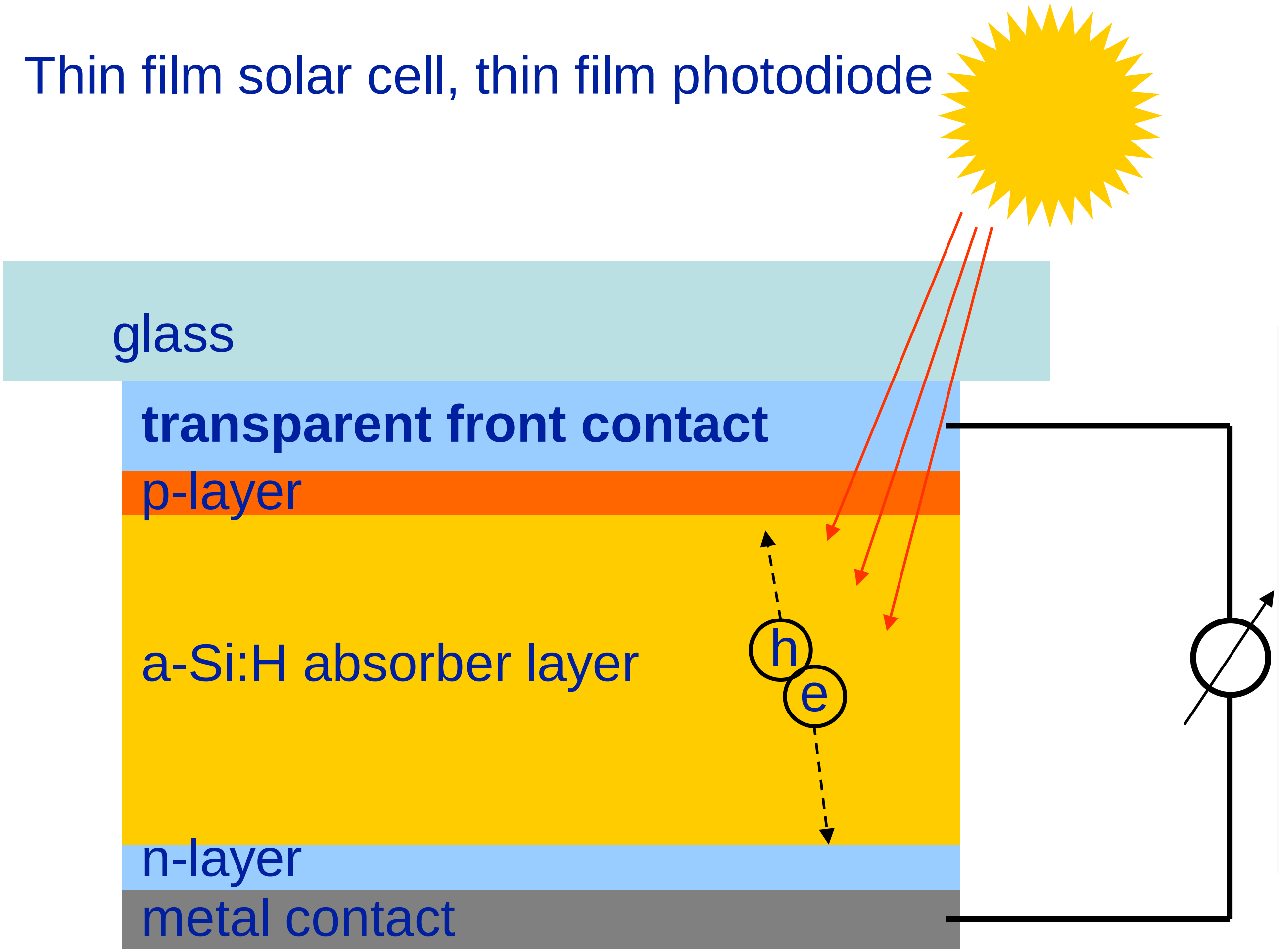
What's inside?

Photocopier: photoconductive coating on printing drum



What's inside?

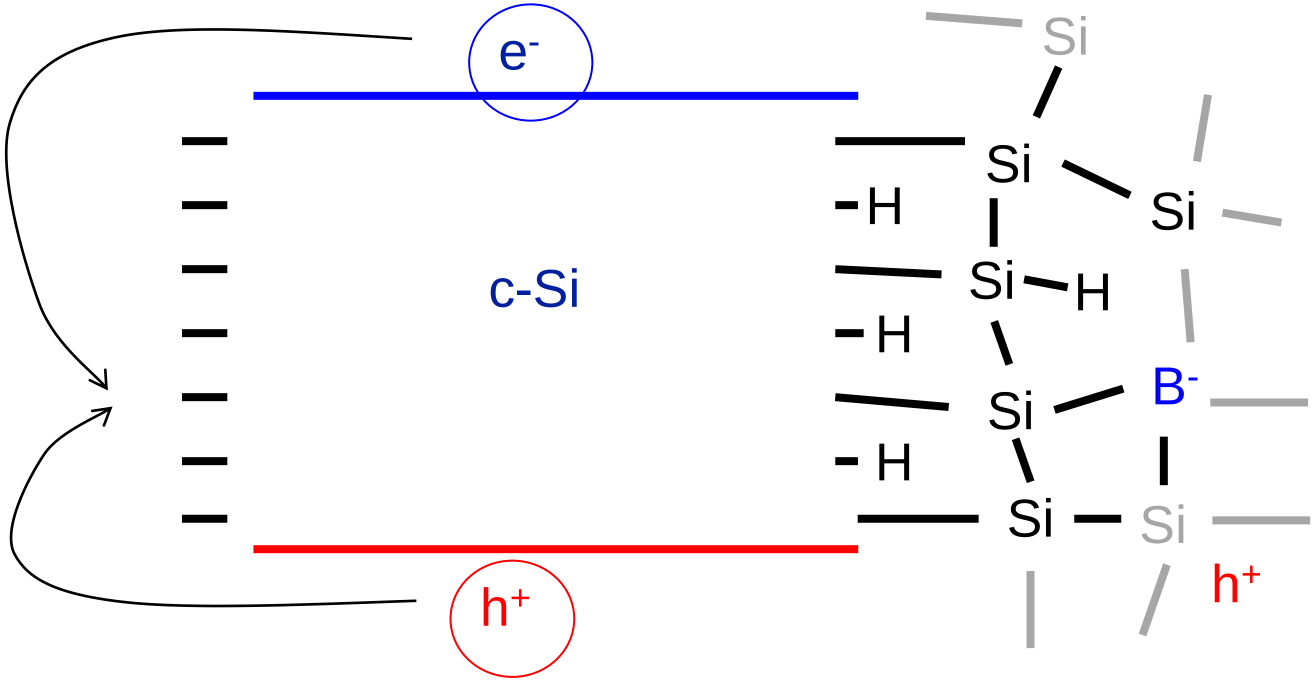
Thin film solar cell, thin film photodiode



e.g. Tissot Solar Touch, Garmin Fenix

What's inside?

Heterojunction solar cell*: passivation **and** contact layers



* used in current world record silicon solar cells, 26.8% (Longi)

Which materials work on large area?

- a-Si:H, a-Se, a-As_2Se_3, organic semiconductors: Xerography (photoconduction)
- a-Si:H: TFT (channel), solar cells (absorber)
- a-Si_3N_4: TFT (gate insulator)
- a-SiC:B, nc-SiOx:B, etc: (transparent p-type contacts)
- a-$Si_{1-x}Ge_x$:H, μc-Si:H: solar cells (low gap absorbers)
- Chalcopyrites (Cu,In,Ga,Se,S compounds): solar cells (absorber)
- CdTe, CdS: solar cells (absorber)
- ZnS, InP, etc: display, lighting
- Metal oxides: transparent contacts

(remember c-Si: max wafer size 12”)

Emerging materials

- Organic semiconductors: OLED, TFT (channel), electroluminescent displays, solar cells
- Metal oxides: TFT (gate insulator and channel), sensors

19" transparent AMOLED (Samsung, 2011)

71 cm x 56 cm, CeeLite

How to grow thin films of these materials?

Thin film manufacturing: core of today's semiconductor industry

Thin film deposition

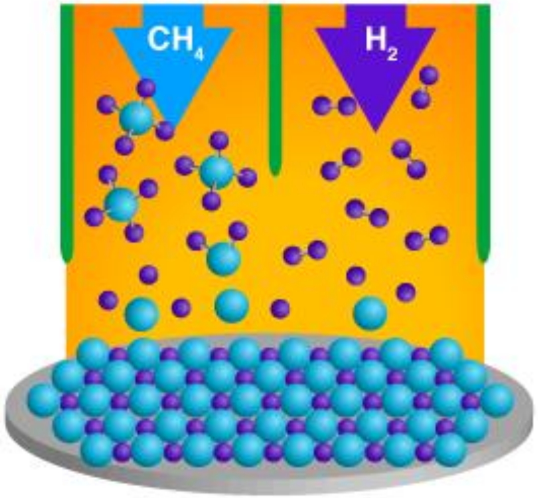
Chemical processes

Use of volatile precursors (fluid or gas) which react at the surface of a substrate.

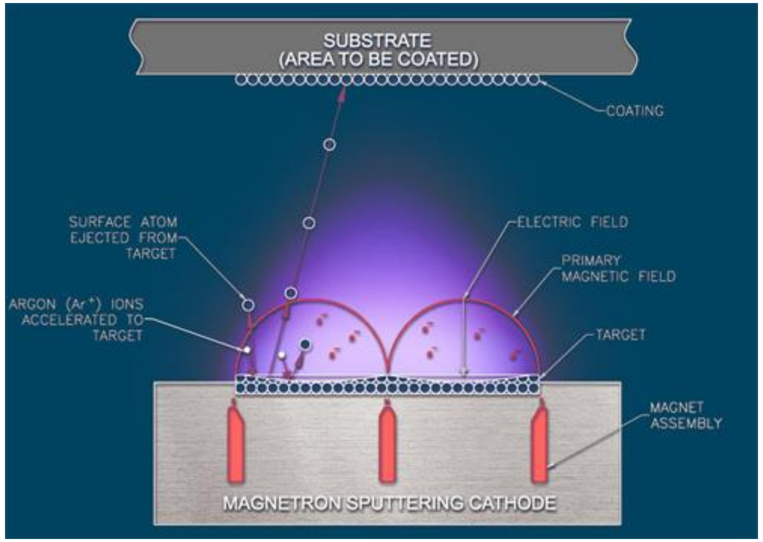
Physical processes

Release from a source and deposition on a substrate using e.g. mechanical or thermodynamic processes.

Chemical Vapor Deposition (CVD)



Substrat



How to grow thin films of these materials?

F.-J. Haug

- Thin film deposition
  - **Chemical processes**
    - Solution
      - solgel
      - electroplating
    - CVD
      - MOCVD
      - PECVD
      - Thermal
      - LP/HP/AP
      - ALD
  - **Physical processes**
    - Evaporation
      - Ion plating
      - Laser ablation (PLD)
      - MBE
      - e-beam evaporation
      - Thermal evaporation
    - Sputtering
      - RF / DC
      - Reactive
      - Magnetron
      - Ion beam

How to grow thin films of these materials?

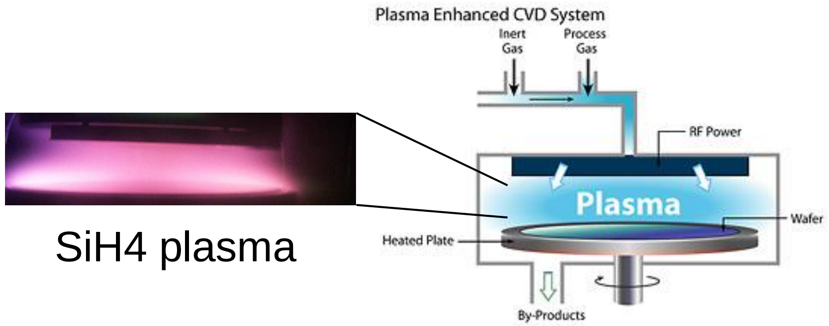
- Thin film deposition
  - **Chemical processes**
    - Solution
      - solgel
      - electroplating
    - CVD
      - MOCVD
      - **PECVD**
      - Thermal
      - LP/HP/AP
      - ALD

PECVD: plasma enhanced chemical vapor deposition

Thin film silicon:

SiH_4 (silane) → Si + 2 H_2

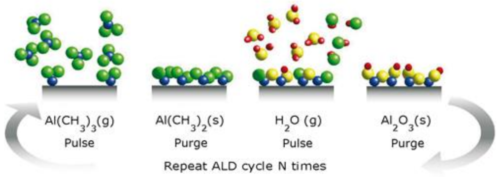
Dopants: PH_3 (phosphine) or B_2H_6 (di-borane)



SiH4 plasma

How to grow thin films of these materials?

- **Thin film deposition**
  - **Chemical processes**
    - Solution
      - solgel
      - electroplating
    - CVD
      - MOCVD
      - PECVD
      - Thermal
      - **LP/HP/AP**
      - **ALD**
  - **Physical processes**
    - Evaporation
      - Ion plating
      - Laser ablation (PLD)
      - MBE
      - **Electron beam**
      - **Thermal**
    - Sputtering
      - **RF / DC**
      - **Reactive**
      - **Magnetron**
      - Ion beam

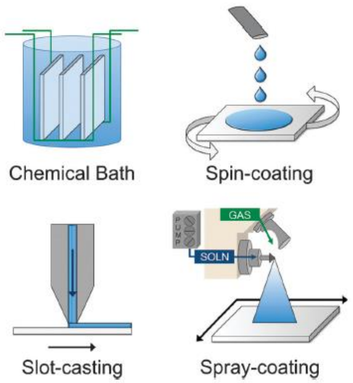


www.beneq.com

Vacuum processes to grow, e.g.,
metal and **metal oxide** thin films

How to grow thin films of these materials?

- Thin film deposition
  - **Chemical processes**
    - Solution
      - **solgel**
      - **electroplating**
    - CVD
      - MOCVD
      - PECVD
      - Thermal
      - LP/HP/AP
      - ALD
  - **Physical processes**
    - Evaporation
      - Ion plating
      - Laser ablation (PLD)
      - MBE
      - Electron beam
      - Thermal
    - Sputtering
      - RF / DC
      - Reactive
      - Magnetron
      - Ion beam



Non-vacuum processes to grow, e.g., **organic semiconductors** and **metal oxide** thin films

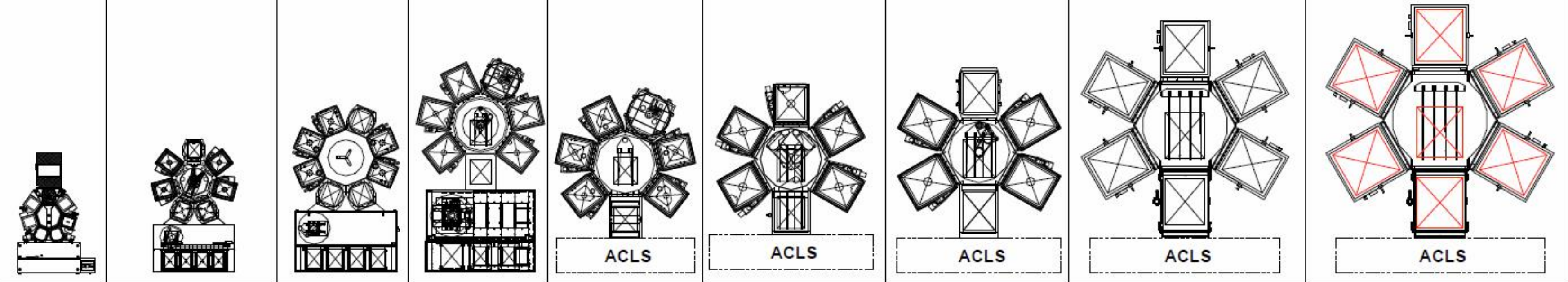
How to grow thin films of these materials?

- Thin film deposition
  - **Chemical processes**
    - Solution
      - solgel
      - electroplating
    - CVD
      - MOCVD
      - PECVD
      - Thermal
      - LP/HP/AP
      - ALD
  - **Physical processes**
    - Evaporation
      - Ion plating
      - Laser ablation (PLD)
      - MBE
      - Electron beam
      - Thermal
    - Sputtering
      - RF / DC
      - Reactive
      - Magnetron
      - Ion beam

Up-scalable techniques?

Scalability

8x 65" panels

	Gen 2	Gen 3 / 3.5	Gen 4	Gen 5	Gen 5	Gen 5.5	Gen 6	Gen 7 / 7.5	Gen 8
1st Release	2/ '93~	4/ '95~	1/ '00~	8/ '01~	6/ '02~	8/ '04~	5/ '03~	7/ '04~	2006
System Layout					ACLS	ACLS	ACLS	ACLS	ACLS
Model Substrate Size (mm)	1600 370x470 400x500	3500 / 4300 / 4300A 550x650 600x720 620x750	5500/5500A 680x880 730x920	10K 1000x1200	15K / 15KA 1100x1250 1200x1300	20K 1300x1500	25K / 25KA 1500x1800 1500x1850	40K / 40KA 1870x2200 1950x2250	50K 2160x2460
Substrate Area	2,000 cm2 (1.00)	4,650 cm2 (2.33 from 1600)	6,716 cm2 (1.44 from 4300)	12,000 cm2 (1.79 from 5500)	15,600 cm2 (1.30 from 10K)	19,500 cm2 (1.25 from 15 K)	27,750 cm2 (1.78 from 15 K)	41,140 cm2 (1.52 from 25 K)	53,136 cm2 (1.21 from 40 KA)
Panel size Inch	10.4	12.1	15 ~ 17	19 ~ 23	21 ~ 24	32W	37W	46W	52W
Panel/sub	4	6	6	6	6	6	6	6	6
Application	Note PC	----------------->	Monitor		----------------->		TV		

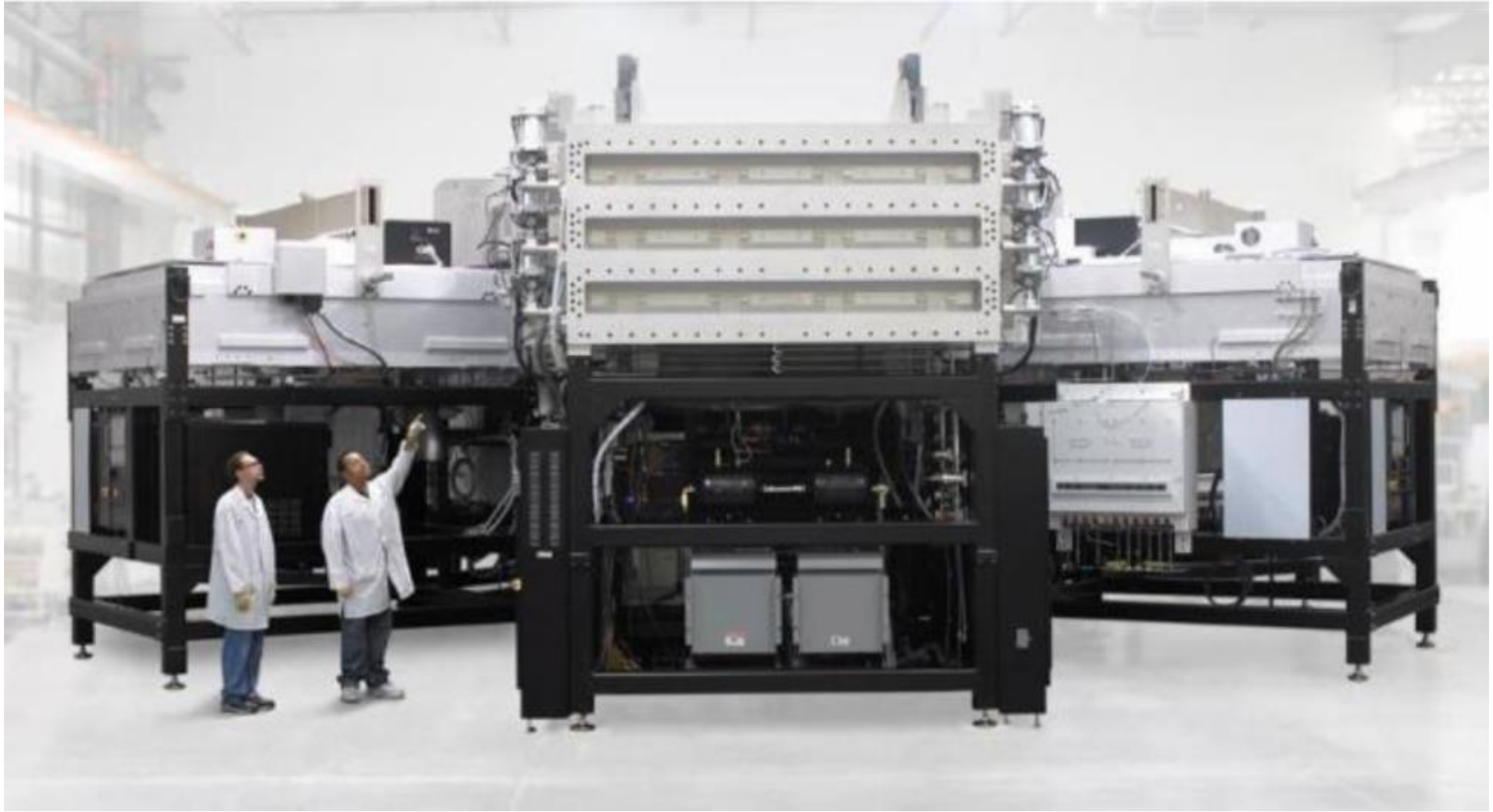
Gen10

(remember:
15": 304x228 mm^2)

Source: Applied Materials

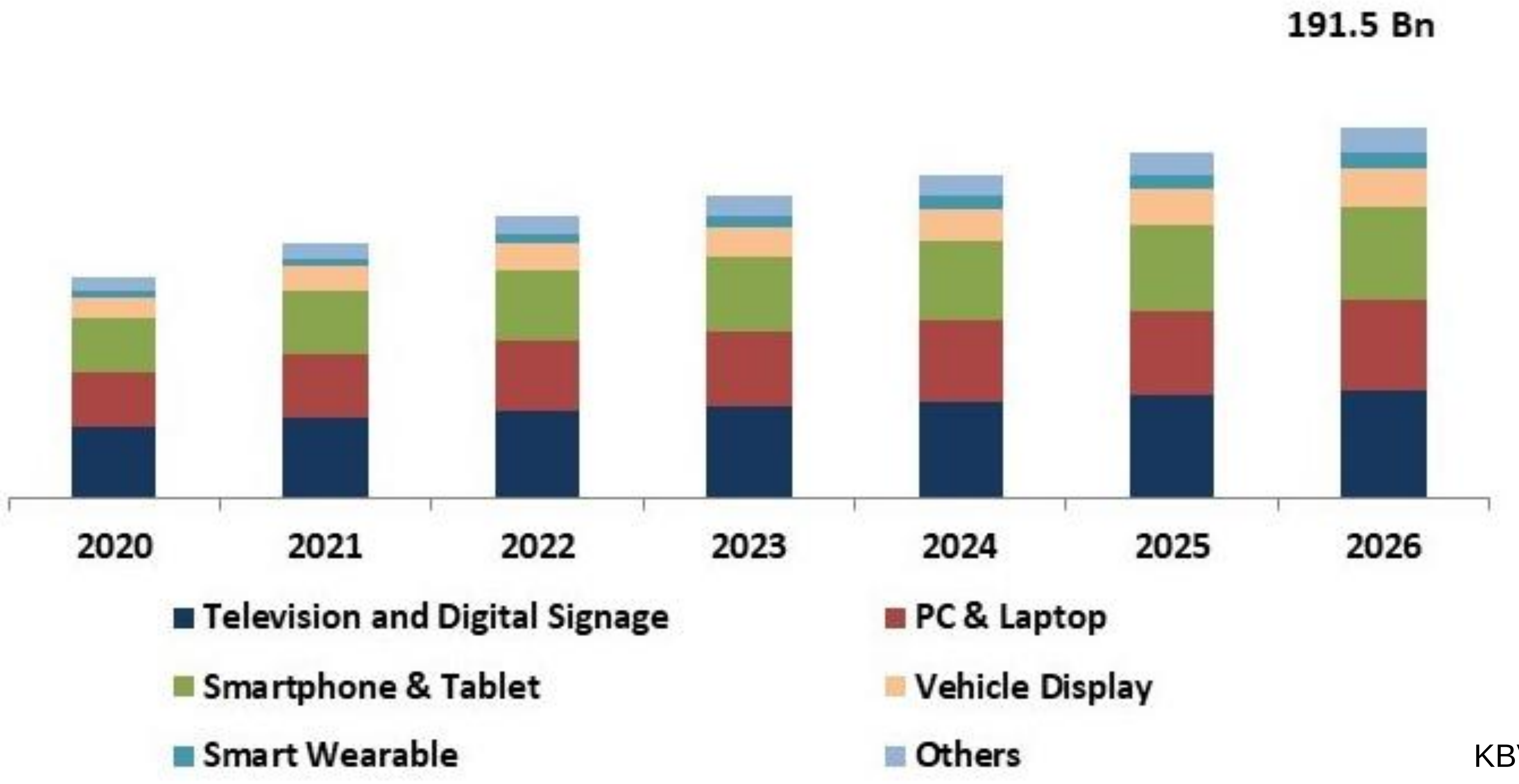
Examples

Gen10 (9 m^2)
PECVD cluster
(AMAT AKT90)



Other suppliers: Leybold, Jusung, Ulvac, etc.

Global display market



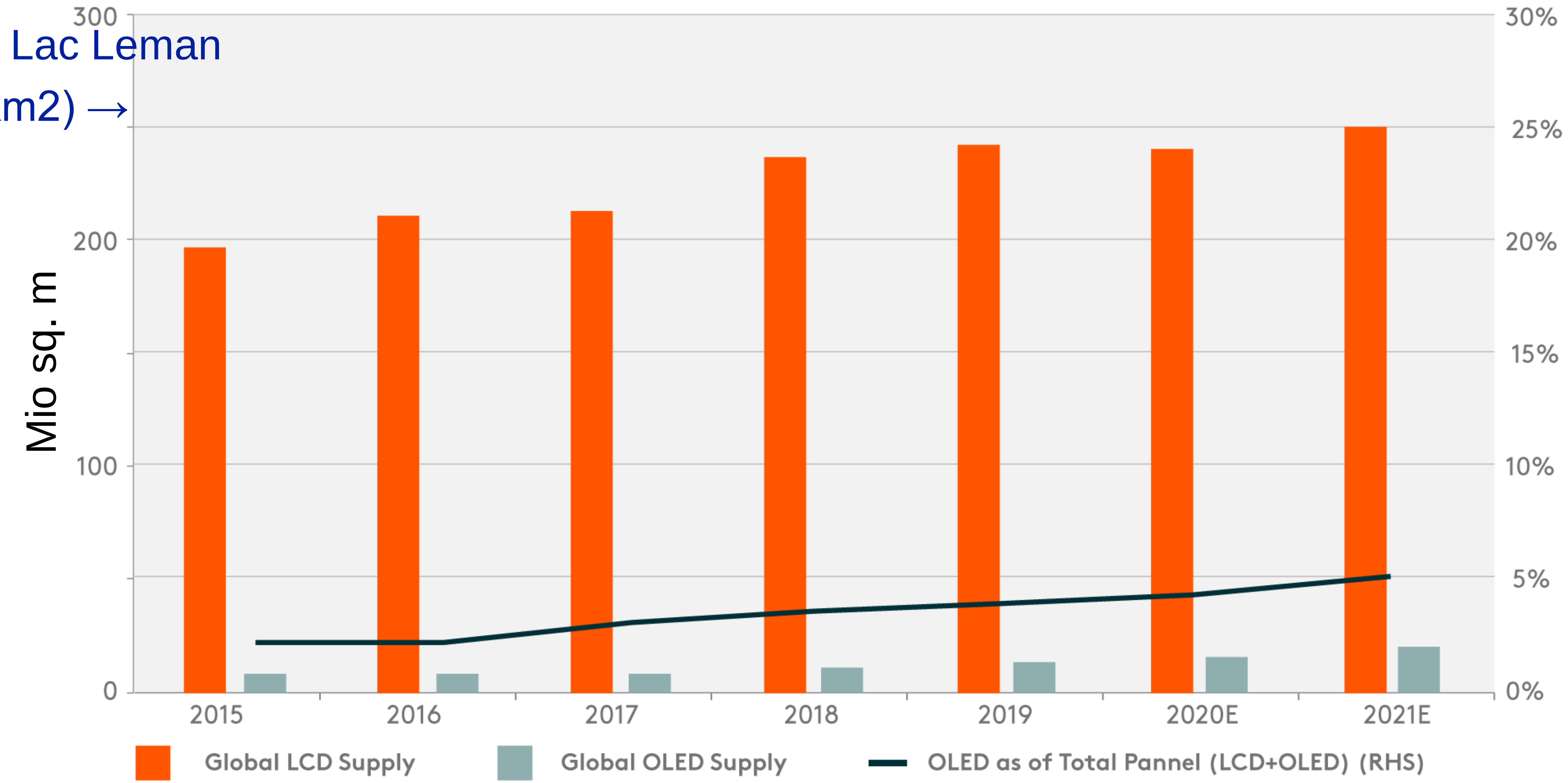
KBV research

strong growth forecasted for vehicle displays

Prospect of TF-Si

half of Lac Leman

(580 km2) →



stdandard

e.g. a-Si

highend

e.g. LCPS or IGZO

MorganStanley

July 2020

From micro- to macroelectronics

F.-J. Haug

Benefits

- Large area fabrication
- Lower processing costs (thin film deposition/coating, printing)
- Device stacking, 3D integration
- Combination of technologies

Drawbacks

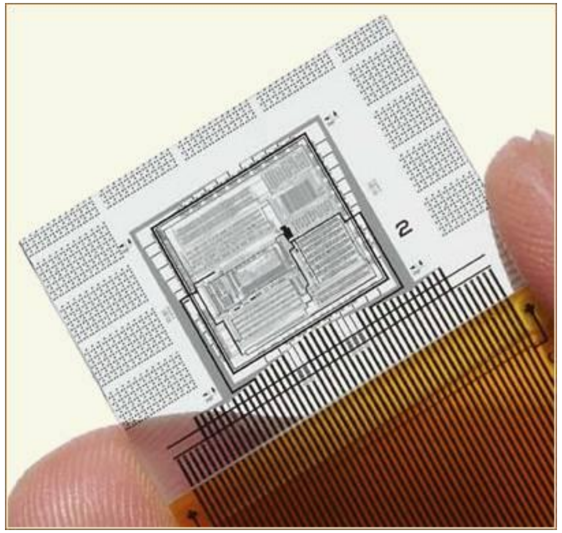
- Process control, non uniformity
- Lower material quality (low mobility, defects,..)
- Lower device performance
- Non standard equipment

Driving forces

- Lower cost
  - Replace «classical electronics/devices» by deposited or printed devices

- Larger devices
  - Equipment scale-up
  - Printing

- New devices / applications
  - Flat panel displays/imagers
  - System on panel
  - Flexible devices



Z80 CPU on glass substrate, 13’000 TFT, Sharp

Samsung Galaxy Z foldable screen

EPFL

Challenge of a-Si channel material

F.-J. Haug

- a-Si is not a unique material
  - only PECVD delivers “good a-Si”
  - properties depend on power/temperature during deposition
- a-Si contains defects (always!)
  - low carrier mobility => TFTs can switch voltages, not currents
  - shallow trap states => TFT channels become conductive only after all defects are filled
  - deep defects act as recombination centres => limited minority carrier transport in solar cells
- a-Si is metastable
  - solar cells: light induced defects (note: effect saturates)
  - TFTs: threshold voltage shift (take care in device design)

Workaround: laser-crystalized poly-Si (LCPS), In-Ga-Zn-O (IGZO)

Transparent Conducting Oxides (TCOs)

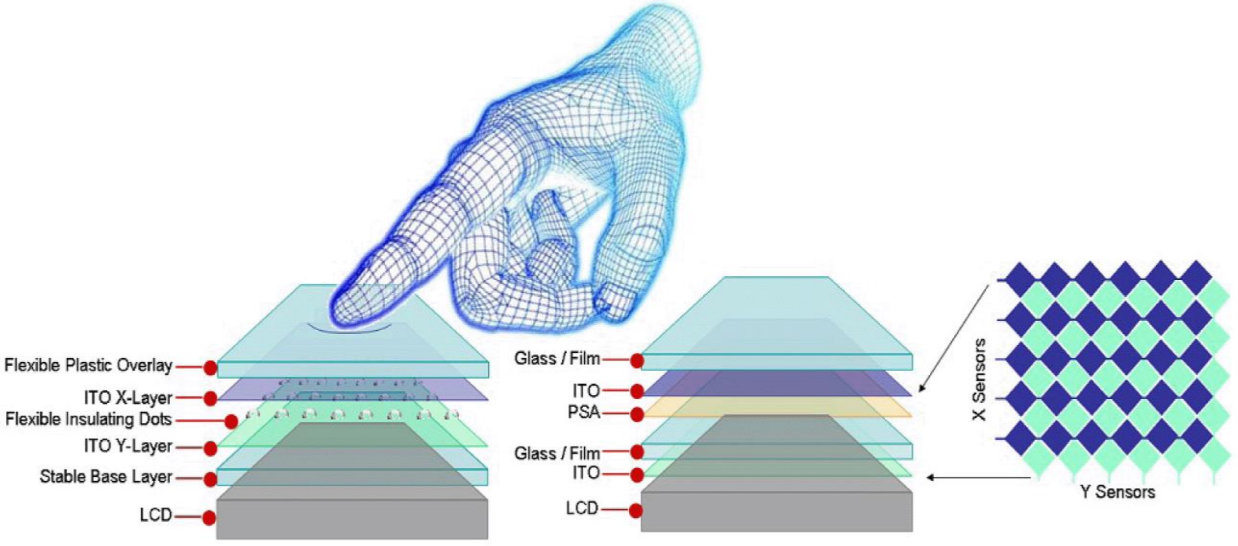
Materials that transmit light and conduct electrical current simultaneously

- ✓ Semiconducting
- ✓ dopable (n-type)
- ✓ Wide band gap
- ✓ Transparent in the VIS and NIR

Application:

Transparent electrode in optoelectronic devices

Use of TCOs: e.g. in touch screens



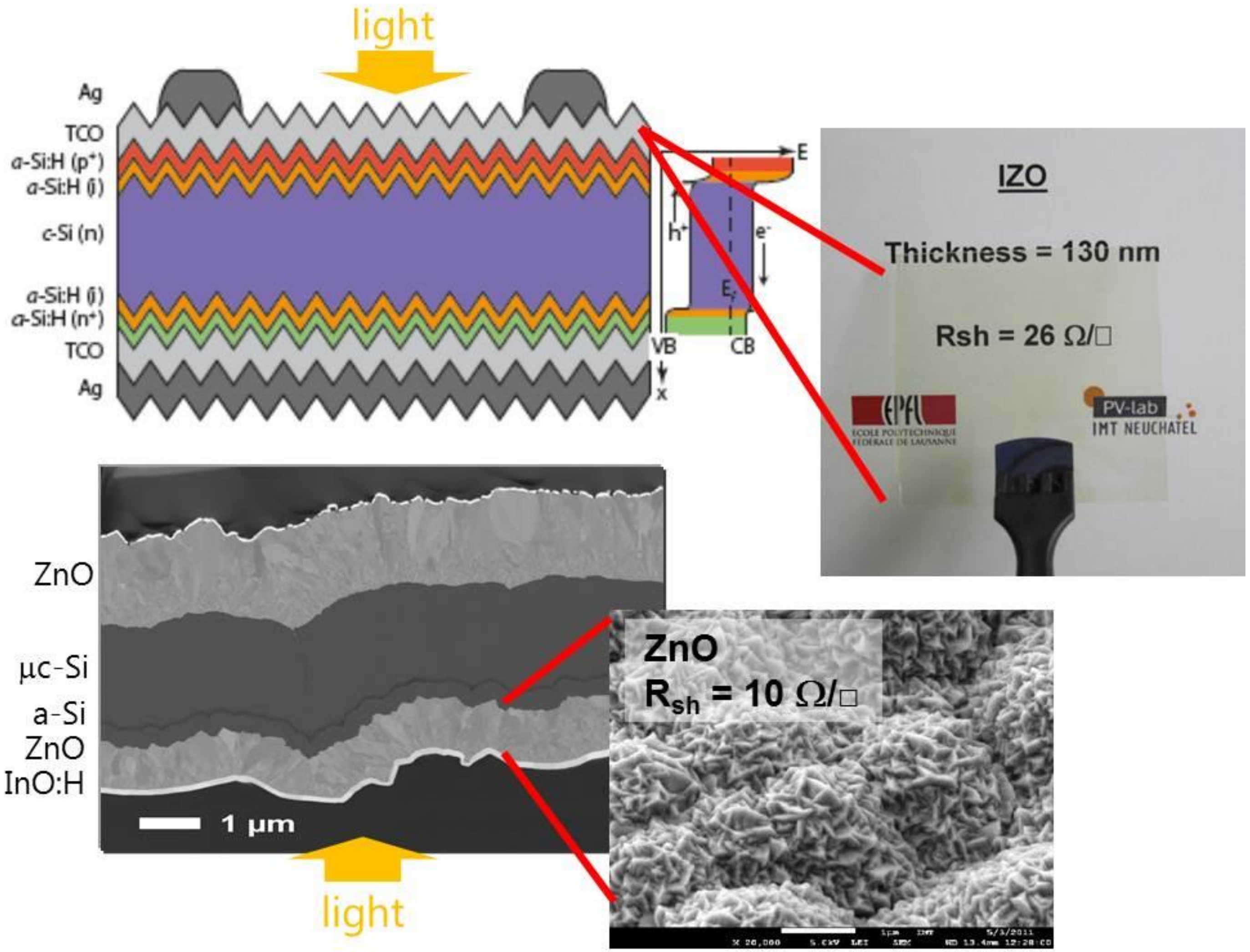
Source:http://www.digikey.com

TCO functionality / requirement

Capacitive detection:
need for conductive layer.

Light should go out of the screen:
need for transparent layer.

Use of TCOs: e. g. in solar cells



<u>Front TCO requirements</u>

Let the light into the solar cells with minimum losses.

- **Low optical absorptance in the UV to red-IR region of the spectrum**

Collection and transport of the photo-generated electron and holes

- **High electrical conductivity**

$$\sigma = eN\mu$$

EPFL

TCOs: where is the challenge?

- ✓ Transparency-conductivity trade off
  - ✓ Increase carrier density limits transmittance in the NIR-IR.
  - ✓ Ideally need to increase mobility instead of carrier density to improve conductivity.

$$\uparrow \boxed{\sigma = eN\mu} \uparrow$$

- ✓ Defects:
  - ✓ Limits electron mobility
  - ✓ Subgap defects: limits transmittance (Vis). Limits TFTs device performance (flexible transparent TFTs).

- ✓ Properties strongly dependent on deposition conditions:
  - ✓ Macroscopic to point defects
  - ✓ Deposition on large area
  - ✓ Process compatibility with devices (e.g. high T process)