



Faculteit Industriële  
Ingenieurswetenschappen

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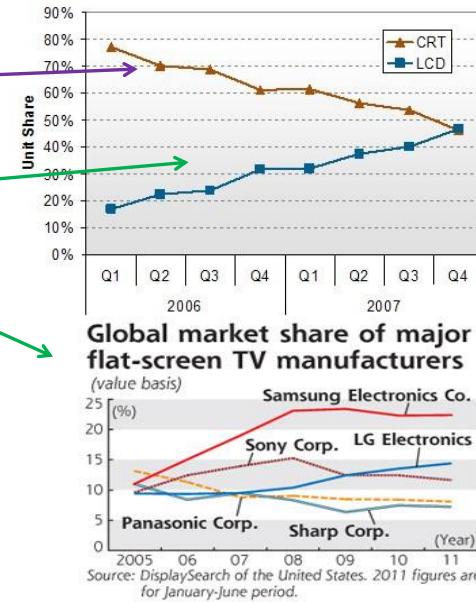
Jan Genoe  
[jan.genoe@kuleuven.be](mailto:jan.genoe@kuleuven.be)

## Materialen in displays

1  
public

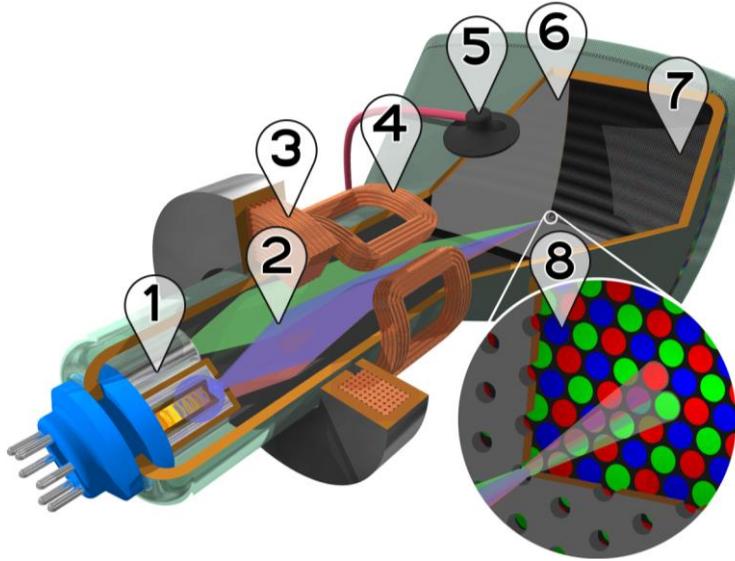
# Overzicht

- Geschiedenis
  - CRT
- Heden
  - LCD
  - DLP
  - OLED displays
- Toekomst
  - E-ink
  - Oprolbare OLED
  - ...



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# 1. Cathode Ray Tube (CRT) Technologie



1. Elektronen kanon
2. Elektronen bundel
3. Focus spoel
4. Afbuig spoel
5. Anode verbinding
6. Masker voor de scheiding van het groene blauwe en rode deel van het beeld
7. Phosphor laag met groene, blauwe en rode zone
8. Detail van de Phosphor laag

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[1] [http://en.wikipedia.org/wiki/Cathode\\_ray\\_tube](http://en.wikipedia.org/wiki/Cathode_ray_tube)

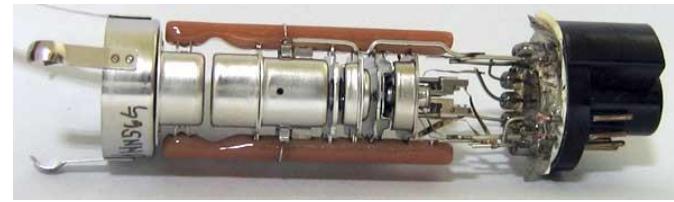
Voor display toepassingen wordt de afbuiging typisch gerealiseerd door een magnetisch veld.

Voor meettoepassingen (e.g. oscilloscoop) wordt de afbuiging gerealiseerd door een elektrisch veld. Dit laatste is preciezer.



## Elektronen kanon

- Thermionische emissie vanuit een warme cathode (filament)
  - vacuum nodig
- Hoge spanningen, hoge velden



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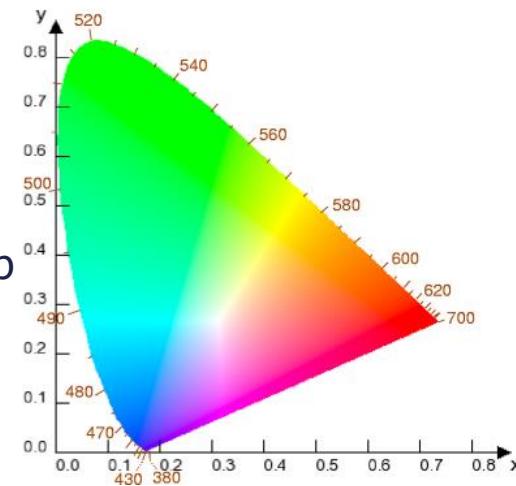
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## Kleurendriehoek

- Zichtbaar spectrum: van 380 nm tot 700 nm
  - Combinaties van
    - Blauw
    - Rood
    - Groen
- leveren alle kleuren op



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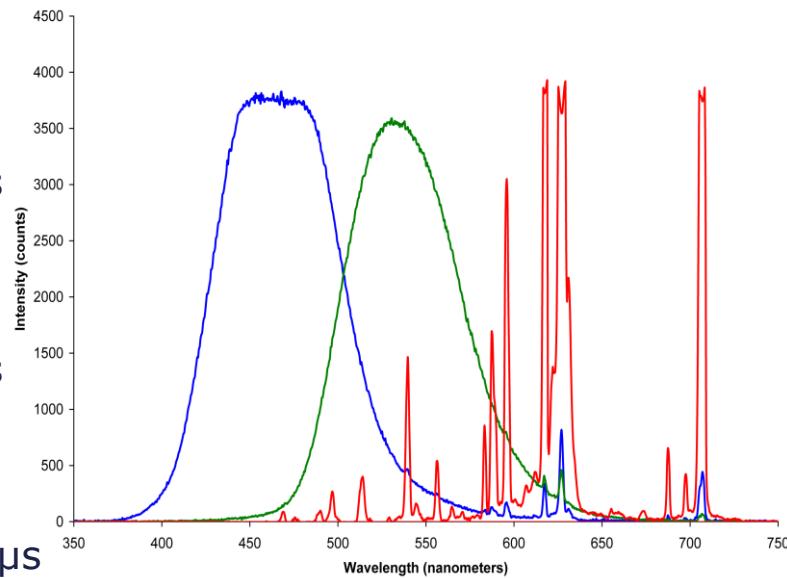
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## Spectrale responsie van de phosphor

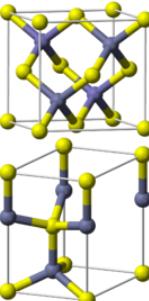
- ✓ ZnS:Cu  
**groen**,  
531 nm  
10%: 35 $\mu$ s
- ✓ ZnS:Ag,  
**blauw**,  
450 nm,  
10%: 80 $\mu$ s
- ✓ Y<sub>2</sub>O<sub>2</sub>S:Eu,  
**rood**,  
626 nm,  
10%: 850  $\mu$ s



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[1] <http://en.wikipedia.org/wiki/Phosphor>

 **Zinksulfide (ZnS)**



- II-VI halfgeleider
- Wide band gap halfgeleider
  - Cubic : 3.54 eV
  - Hexagonal : 3.91 eV
- Kan zowel p- als n-type gedopeerd worden
- Enkele ppm maken het tot een phosphor
  - Ag (blauw)
  - Cu (groen)
  - Mn (oranje)



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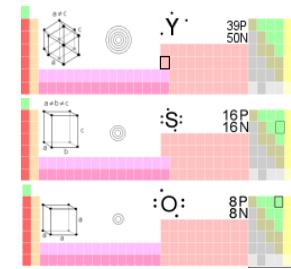
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- [1] [http://en.wikipedia.org/wiki/Zinc\\_sulfide](http://en.wikipedia.org/wiki/Zinc_sulfide)
- [2] <http://en.wikipedia.org/wiki/Silver>
- [3] <http://en.wikipedia.org/wiki/Copper>
- [4] <http://en.wikipedia.org/wiki/Manganese>
- [5] <http://en.wikipedia.org/wiki/Sulfur>



## $\text{Y}_2\text{O}_2\text{S}:\text{Eu}$

- Yttrium oxide sulfide



- Gedopeerd met Europium



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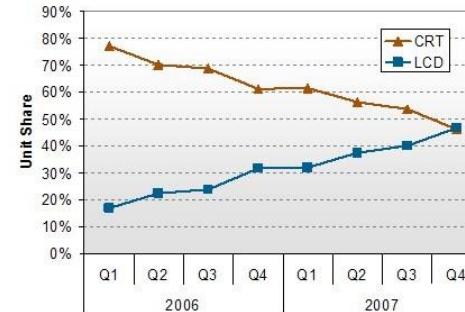
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[1] <http://en.wikipedia.org/wiki/Europium>

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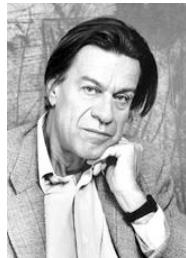
- Geschiedenis
  - CRT
- Heden
  - LCD
  - DLP
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  - OLED displays
  - Oprolbare OLED





## LCD displays

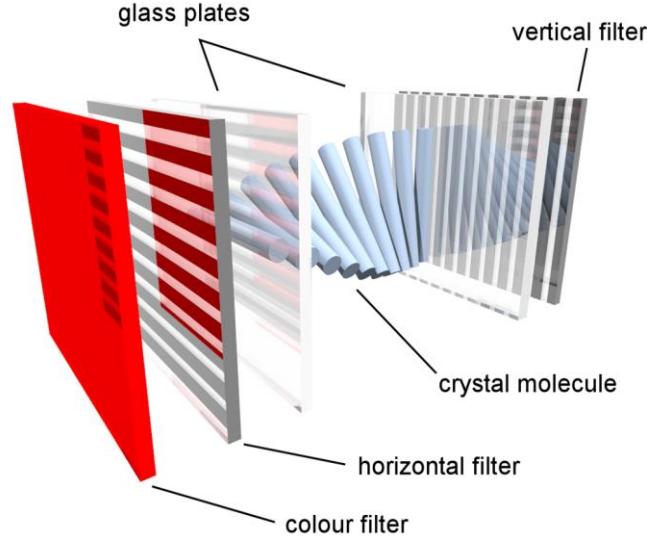
- Nobelprijs Physica 1991



Pierre-Gilles de Gennes



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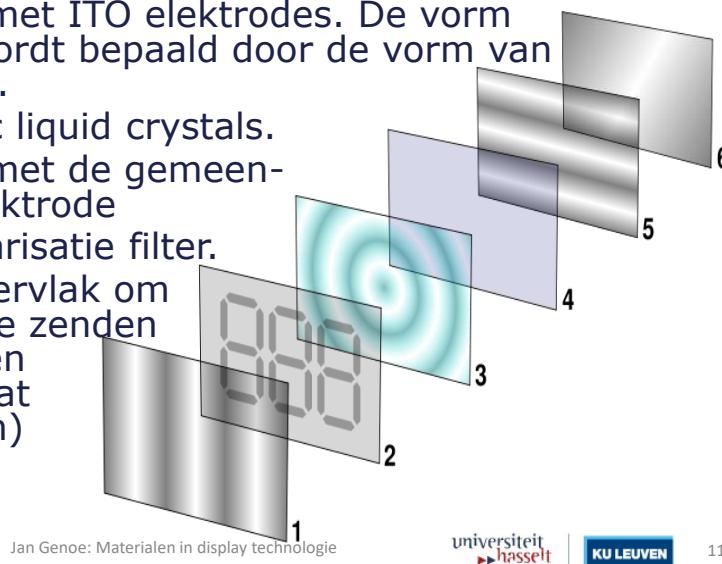
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[1] [http://www.nobelprize.org/nobel\\_prizes/physics/laureates/1991/gennes-bio.html](http://www.nobelprize.org/nobel_prizes/physics/laureates/1991/gennes-bio.html)



## Spiegelend twisted nematic LCD displays

1. Verticale filter film om het invallend licht te polariseren
2. Glas substraat met ITO elektrodes. De vorm van de pixels wordt bepaald door de vorm van deze elektrodes.
3. Twisted nematic liquid crystals.
4. Glas substraat met de gemeenschappelijke elektrode
5. Horizontale polarisatie filter.
6. Spiegelend oppervlak om het licht terug te zenden (in geval van een backlit LCD, staat hier de lichtbron)



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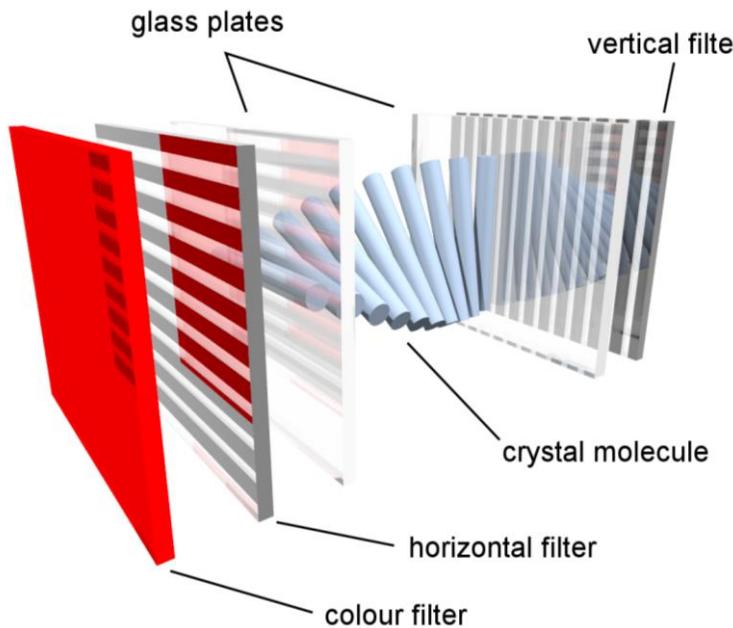
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## LCD displays met kleuren filter



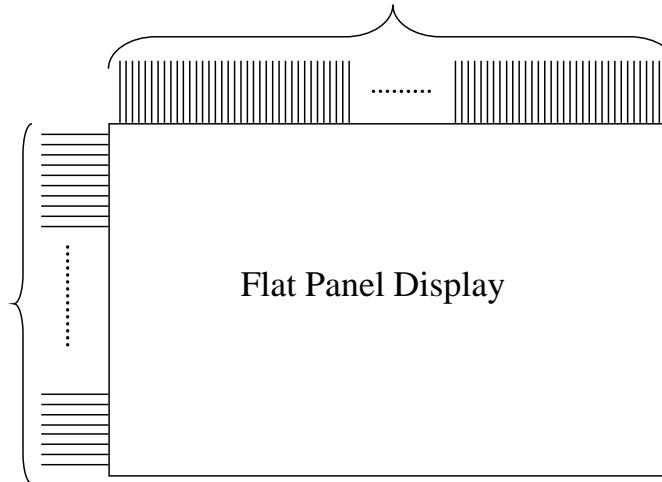
# Structuur van een Flat Panel Display

De 3 kleuren worden tezamen aangestuurd

Verticale lijnen worden tegelijk aangestuurd van  $3 \times 640$  (low end) tot  $+3 \times 1920 (=5760)$  (high end) lijnen

Horizontale lijnen worden 1 voor 1 aangestuurd

van 480 (low end) tot  $+1080$  (high end) lijnen



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Bij het ontwerpen van de ICs die een Flat Panel Display aansturen vragen de drivers van de verticale lijnen het meeste aandacht, en dit omwille van verschillende redenen:

- De horizontale lijnen worden slechts één per één aangestuurd, terwijl de verticale lijnen tegelijk worden aangestuurd.
- De horizontale lijnen dienen slechts een kleine gate capaciteit op te laden, terwijl de verticale lijnen de capaciteit van de pixels zelf moeten opladen.
- ...

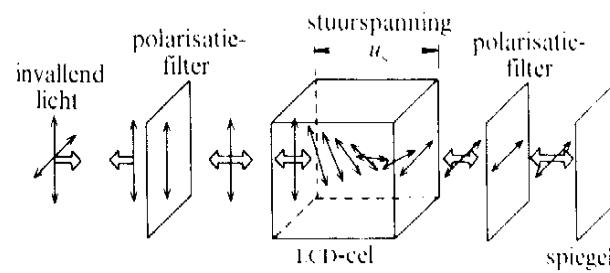
Vandaar dat we in dit deel dieper gaan ingaan op het ontwerp van de drivers van de verticale lijnen.

Typisch zijn er tot 10 drivers voor de verticale lijnen nodig per scherm.



## Werkingsprincipe van een LCD pixel

- Twee polarisatiefilters zijn  $90^\circ$  verdraaid.
- De stuurspanning over het vloeibaar kristal bepaalt de draaihoek.
- Als de draaihoek overeenkomt met de  $90^\circ$  draaiing van de filters wordt het licht doorgelaten



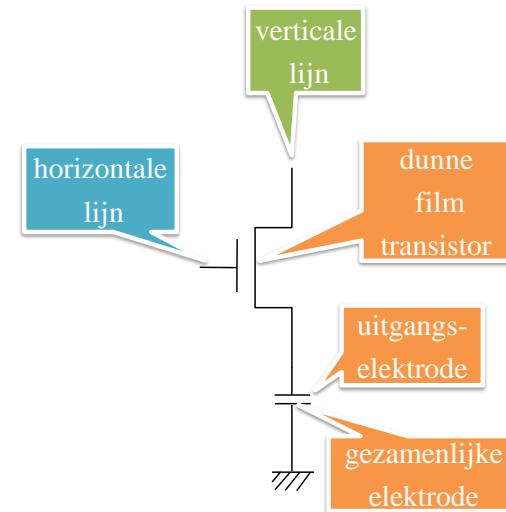
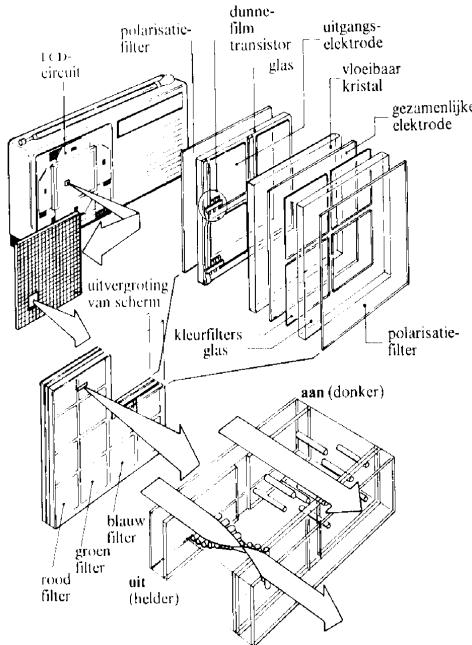
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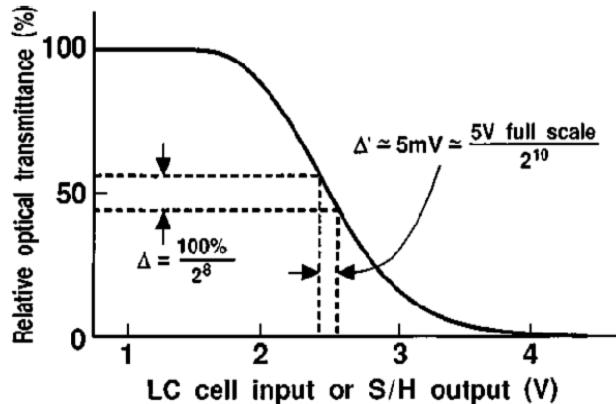
## Uitwerking en equivalent model



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## Transparantie van een vloeibaar kristal in functie van de spanning

De spanning over de cel moet tussen 1.5 en 4.5 Volt kunnen variëren



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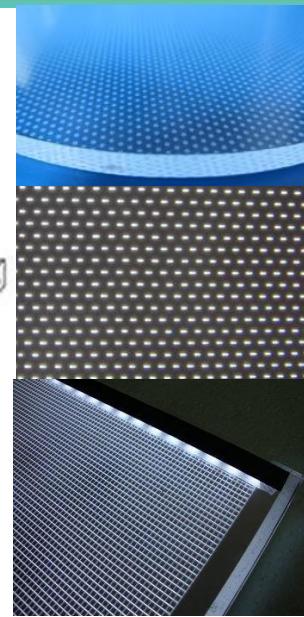
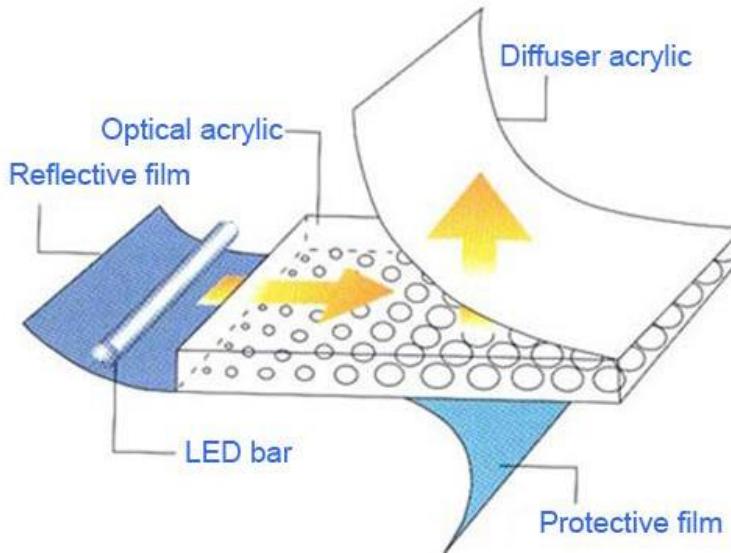
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We merken op dat de relatie tussen de spanning over de liquid crystal cell en de hoeveelheid licht dat erdoor gaat niet perfect linear is, vooral voor de hoge en de lage spanningen. Hierdoor gaan er bij de weergave van zwarte of donkere kleuren belangrijke veranderingen optreden en zal het moeilijk zijn een hoge contrast ratio te bekomen.

Daarnaast is het aantal grijswaarden per kleur natuurlijk sterk afhankelijk van de voltage resolution van de hoge snelheid (video rate) digitaal naar analog omzetter. 8 bit kleurresolutie vereist 5 mV spanningsresolutie.



## Light Guide plate (LEDS)



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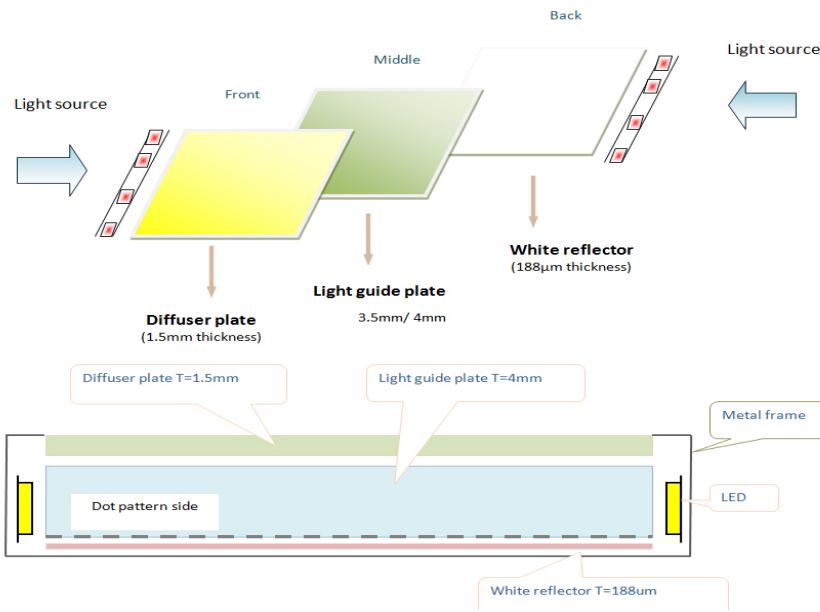
17

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- [1]Y. K. Park, J.-Y. Joo, C. Lee, and S.-K. Lee, "Design and fabrication of a light emitting diode-based diffuser sheet-less light guide plate for lighting applications," International Journal of Precision Engineering and Manufacturing, vol. 14, no. 6, pp. 1017–1022, Jun. 2013.



# Light Guide plate (LEDS)



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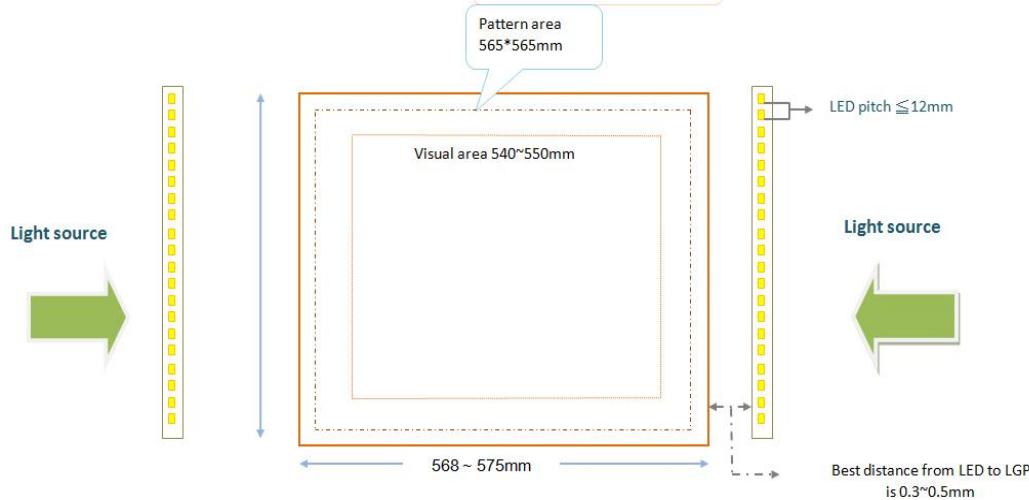
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## Light Guide plate (LEDS)

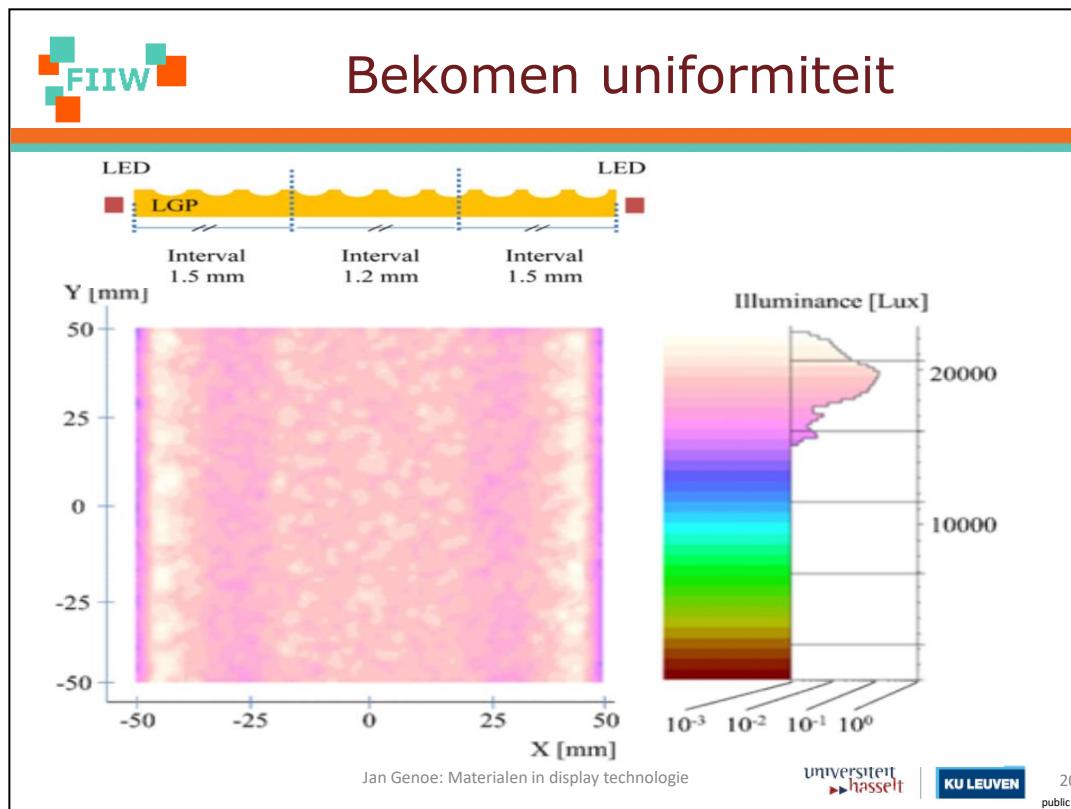


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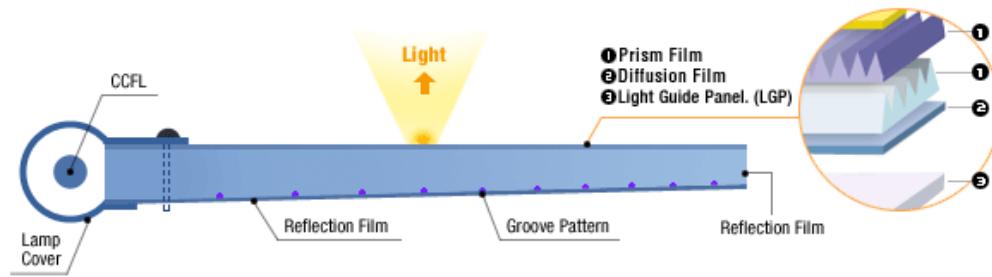
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[1]Y. K. Park, J.-Y. Joo, C. Lee, and S.-K. Lee, "Design and fabrication of a light emitting diode-based diffuser sheet-less light guide plate for lighting applications," International Journal of Precision Engineering and Manufacturing, vol. 14, no. 6, pp. 1017–1022, Jun. 2013.



## Light Guide plate (TL)



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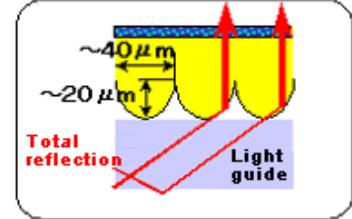
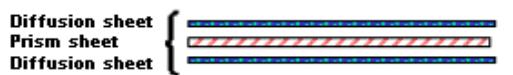


# MiraBright

## Construction of earlier devices



## Construction of the MIRABRIGHT



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## Overzicht

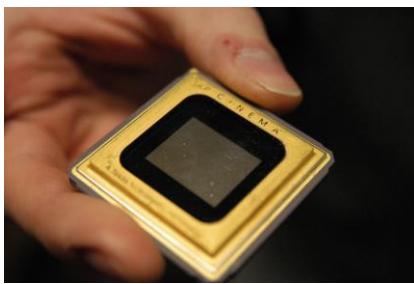
- Geschiedenis
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Ik skip bewust plasma displays. Zij zijn momenteel niet meer relevant.



## Digital Light Processing (DLP) technologie



- Micro-spiegels:  
MEMS technologie  
op silicium
- Implementaties
  - Kleurenwiel
  - 3-chips
  - 3- LEDs

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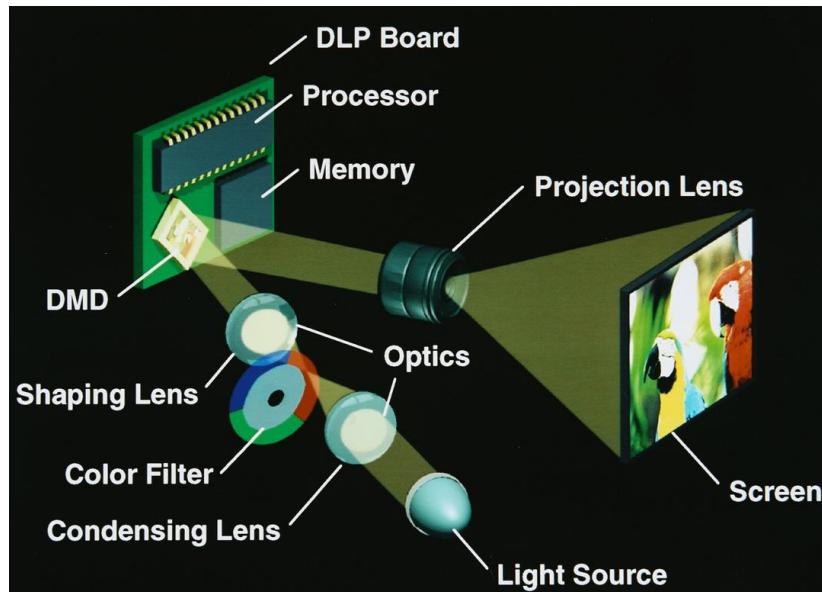
24

[1] <http://en.wikipedia.org/wiki/DLP>

[2] <http://www.dlp.com/tech/what.aspx>



## DLP kleurenwiel implementatie



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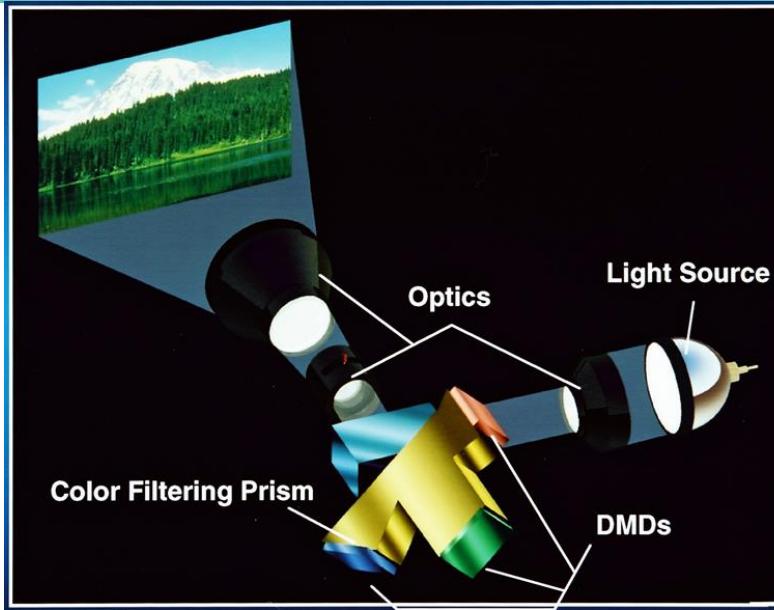
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## DLP 3 chip implementatie



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## DLP rear projection systems: voorbeeld

- Samsung HL-S5679W 56-inch LED DLP HDTV
  - Met kleurenwiel



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## DLP (bioscoop en mini) projector



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## Projectors in GSMS



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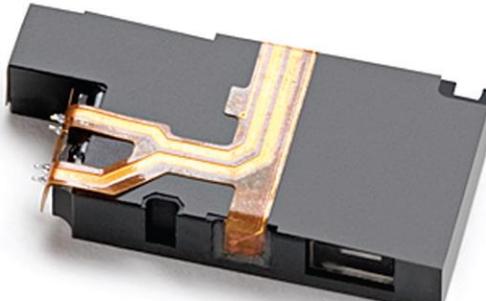
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[1] IEEE spectrum, may 2010, pp37



## Projectors in GSMS en fototoestellen



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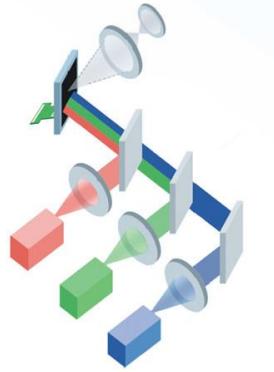
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[1] IEEE spectrum, may 2010, pp37



## voorbeelden



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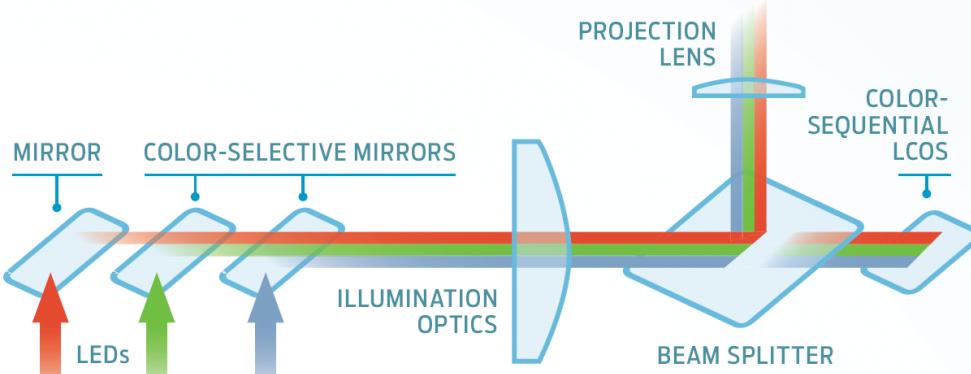
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## Projectors in GSMS



Spiegelend Liquid Crystal on silicon (LCOS) wordt door de 3 LEDs om beurten verlicht.

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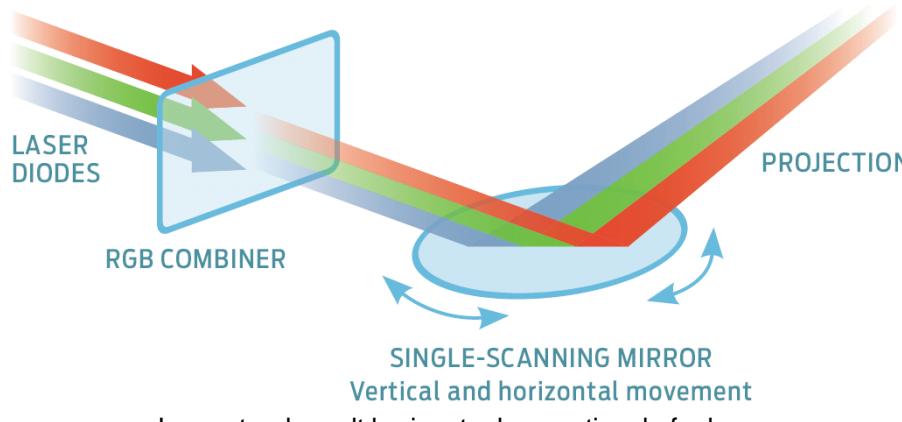
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[1] IEEE spectrum, may 2010, pp37



## Projectors in GSMS



Laserstraal wordt horizontaal en verticaal afgebogen.

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[1] IEEE spectrum, may 2010, pp37



## voorbeelden



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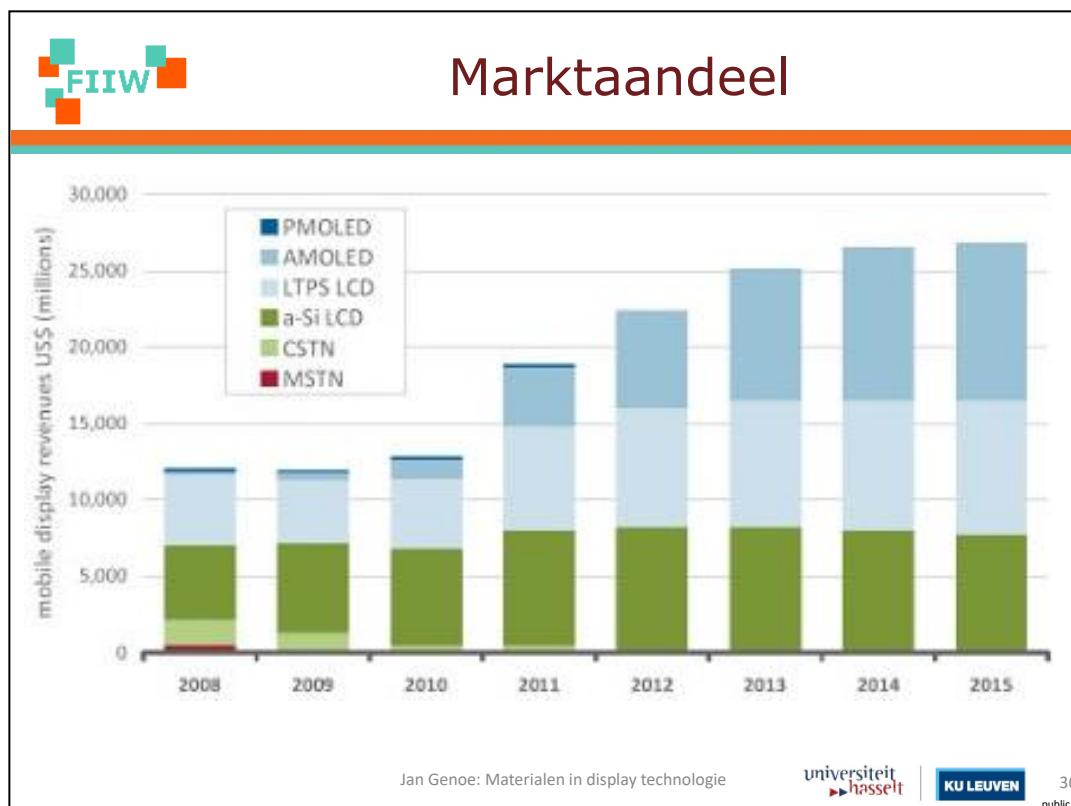
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## Overzicht

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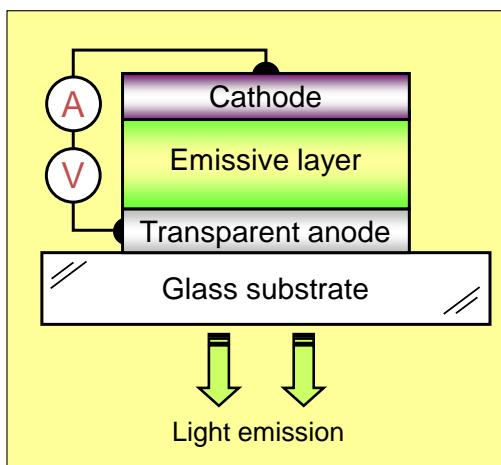
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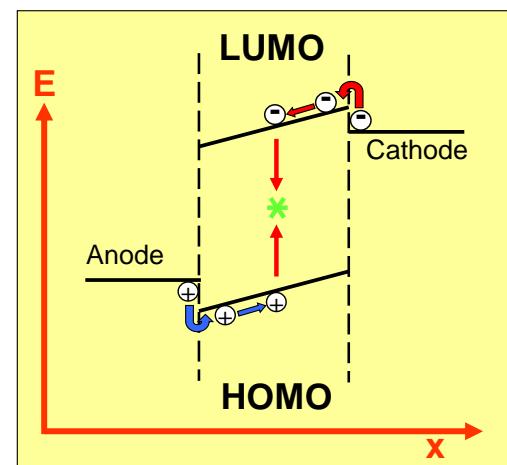


# Organic Light Emitting Diodes

Device structuur



Device energie diagramma



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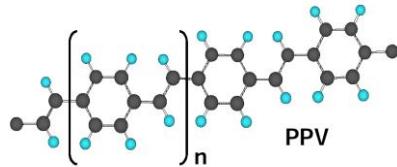
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## Organic semiconductors: Twee varianten

### Polymers



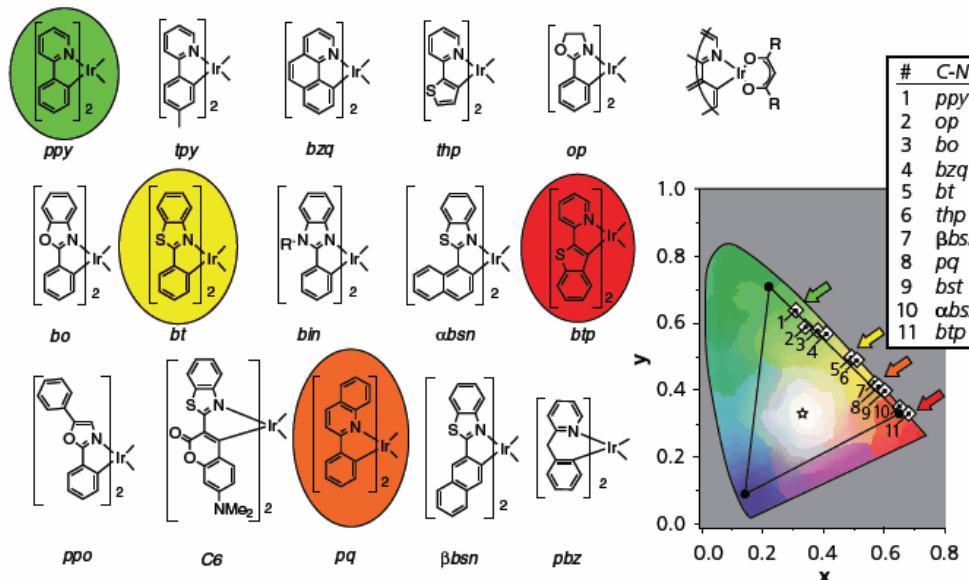
Technologie: Liquid Processing (Spin-On, Printing)

### Small-Molecules



Technologie: opdamping

## Voorbeeld: Ir-based organometallic dopants



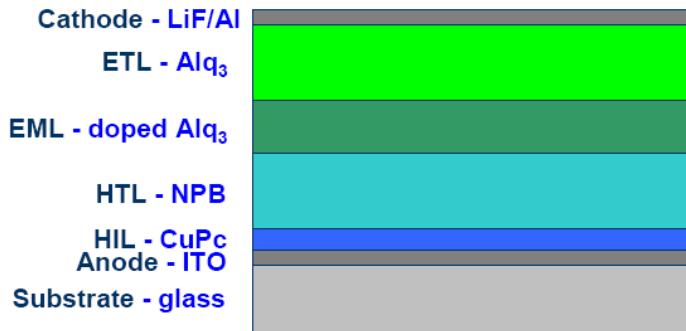
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[1] <http://www.sigmaaldrich.com/technical-documents/articles/material-matters/achieving-high-efficiency.html>



## Typisch lagenstructuur kleine moleculen

### Small molecule

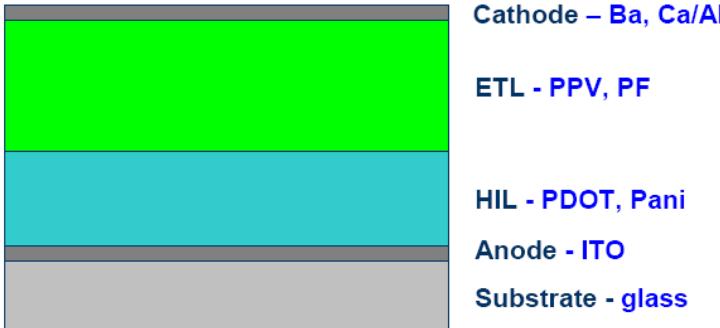


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↓  
↓  
↓  
↓  
**Multi-layer structure  
made all in vacuum**



## Typische lagenstructuur: polymeren

Polymer



Cathode – Ba, Ca/Al

ETL - PPV, PF

HIL - PDOT, Pani

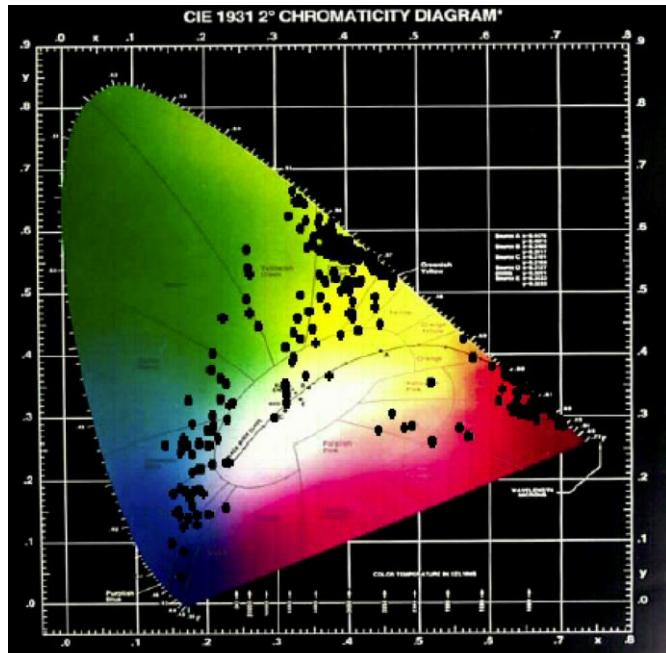
Anode - ITO

Substrate - glass

Bilayer structure  
made from solution



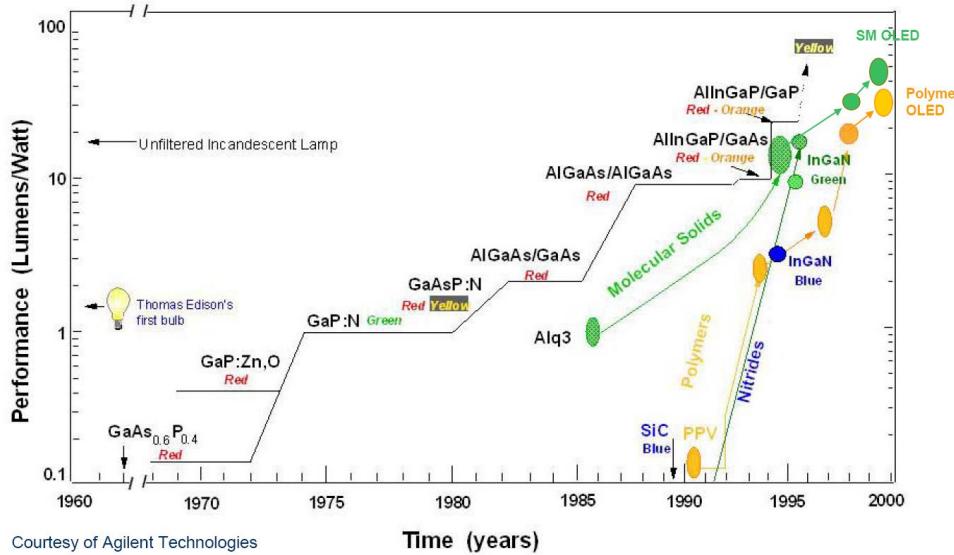
## Punten in de kleurendriehoek



Elke OLED kan  
weergegeven door  
een punt in de  
kleurendriehoek

We moeten 3  
OLED selecteren  
die een zo groot  
mogelijke driehoek  
vormen.

## Efficiëntie OLEDs



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[1] J. Sheats, Science 273 (1996) 884.



## OLED voordelen



**Veel dunner**



**Grote kijkhoek**



**Helderheid en kleur**

**Veel lager energieverbruik**

Source: Kodak

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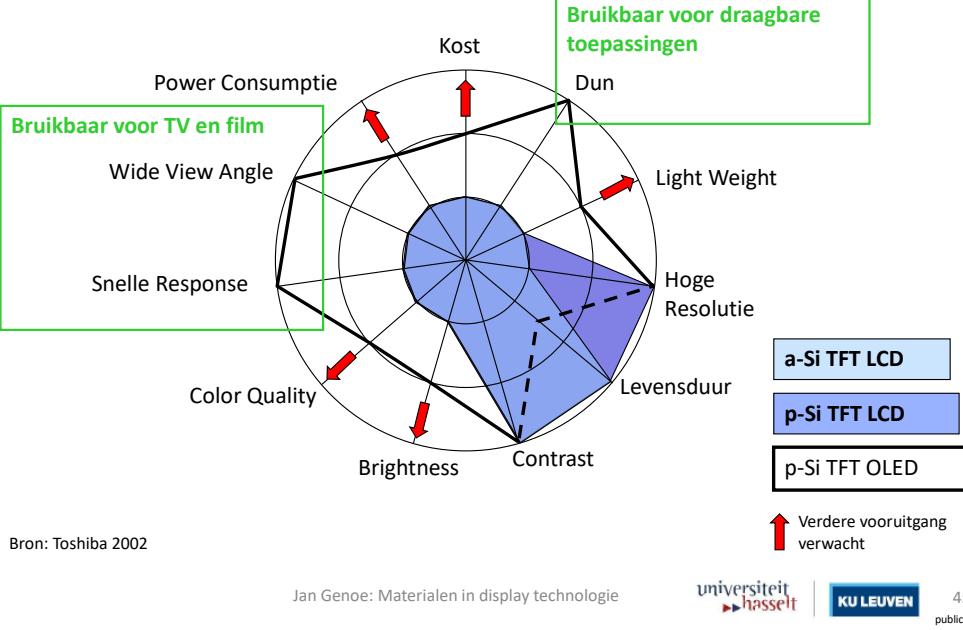
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# OLED Performance





The image shows a woman in a white blouse and orange skirt holding a Samsung 40-inch OLED TV. The TV is displaying a vibrant image of a person's face. The background features a repeating 'wise view' logo.

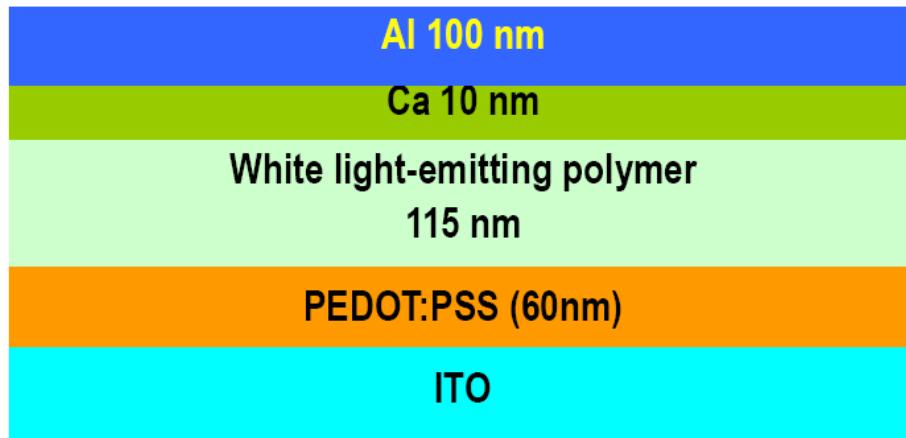
OLED  
mogelijkheden:  
Samsung 40" TV  
display

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## Witte OLEDs (1) lagenstructuur



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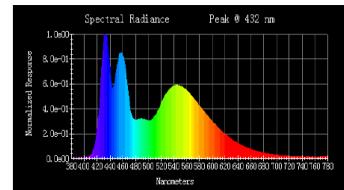
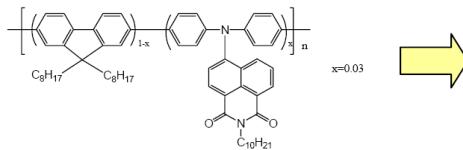
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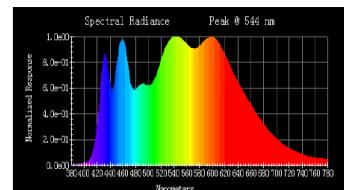
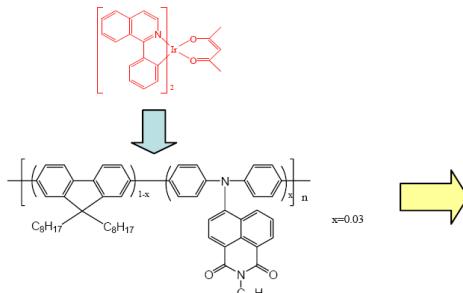
The FIIW logo consists of the acronym "FIIW" in a bold, black, sans-serif font. Behind the letters are four overlapping squares: two teal squares at the top and two orange squares at the bottom-right.

## Witte OLEDs (1) Materialen

### I) Single layer WPLED



Veel blauw,  
te weinig  
rood en  
groen



## Kleine toevoeging

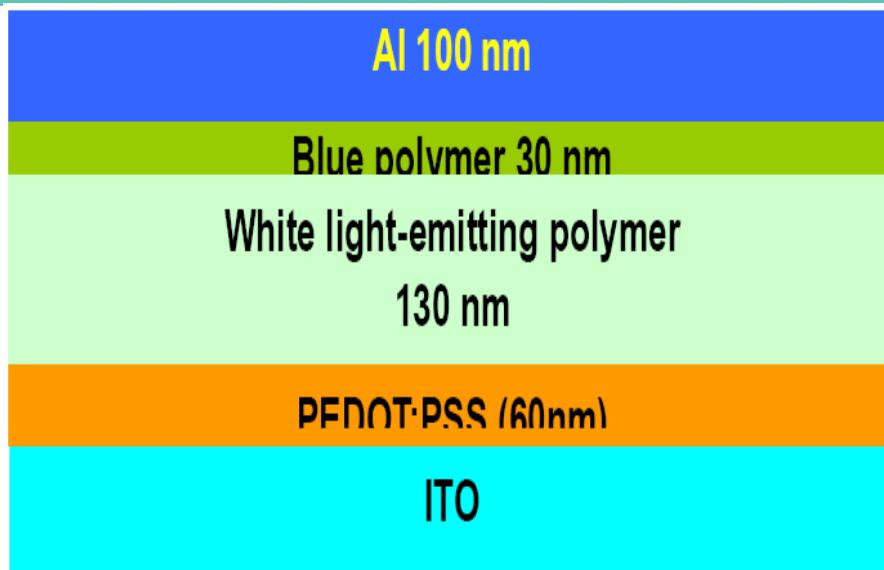
Alle kleuren  
evenveel

Jan Genoe: Materialen in display technologie

- [1] White polymeric light-emitting diodes with high color rendering Index, **Xiaodi Niu**, Liang Ma, Bing Yao, Junqiao Ding, Guoli Tu, Zhiyuan Xie,\* and Lixiang Wang, *Applied Physics Letters* **2006**, *89*, 213508.
  - [2] Efficient multilayer white polymer light-emitting diodes with aluminum cathodes. **Xiaodi Niu**, Chuanjiang Qin, Baohua Zhang, Junwei Yang, Zhiyuan Xie,\* Yanxiang Cheng, and Lixiang Wang, *Applied Physics Letters* **2007**, *90*, 203513



## Witte OLEDs (2) lagenstructuur



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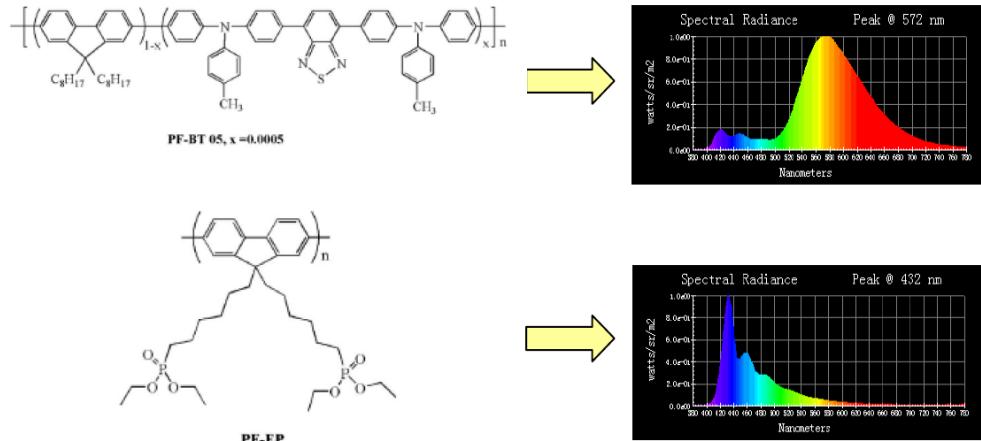
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## Witte OLEDs (2) materialen afzonderlijk

### II) Double emissive layer WPLED with Al cathode



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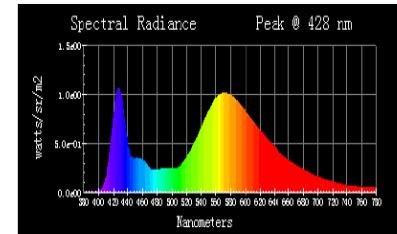
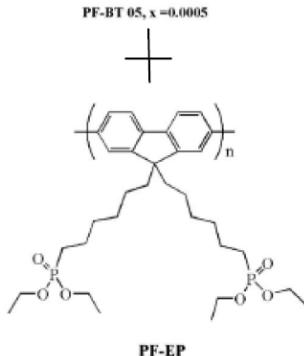
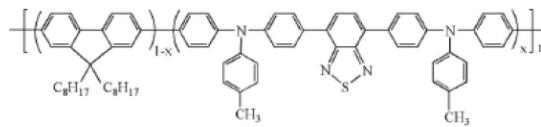
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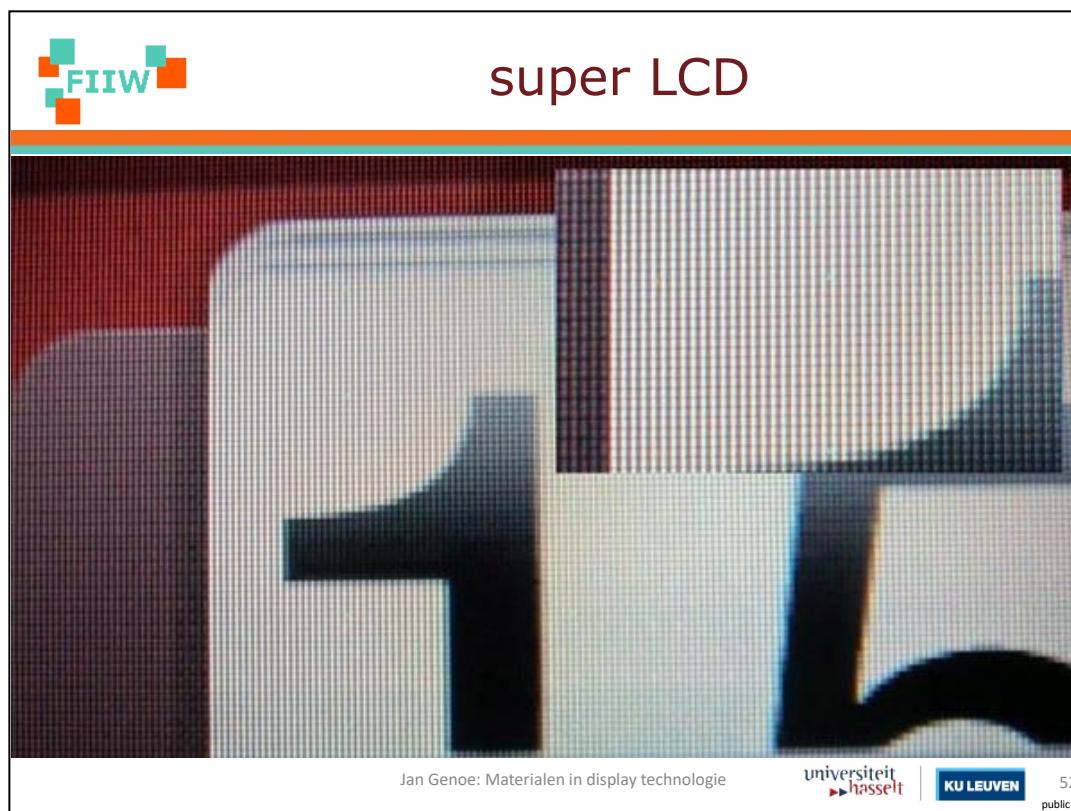
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## Witte OLEDs (2) materialen samen



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## Samsung AM-OLED



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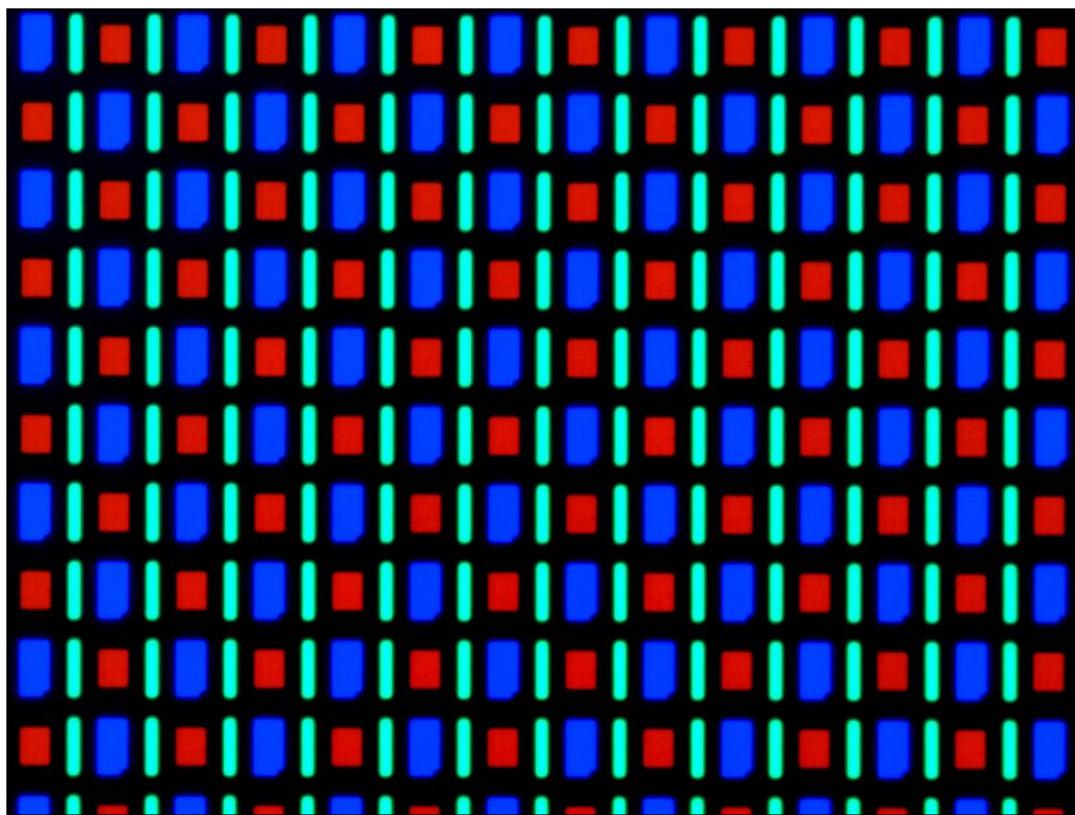
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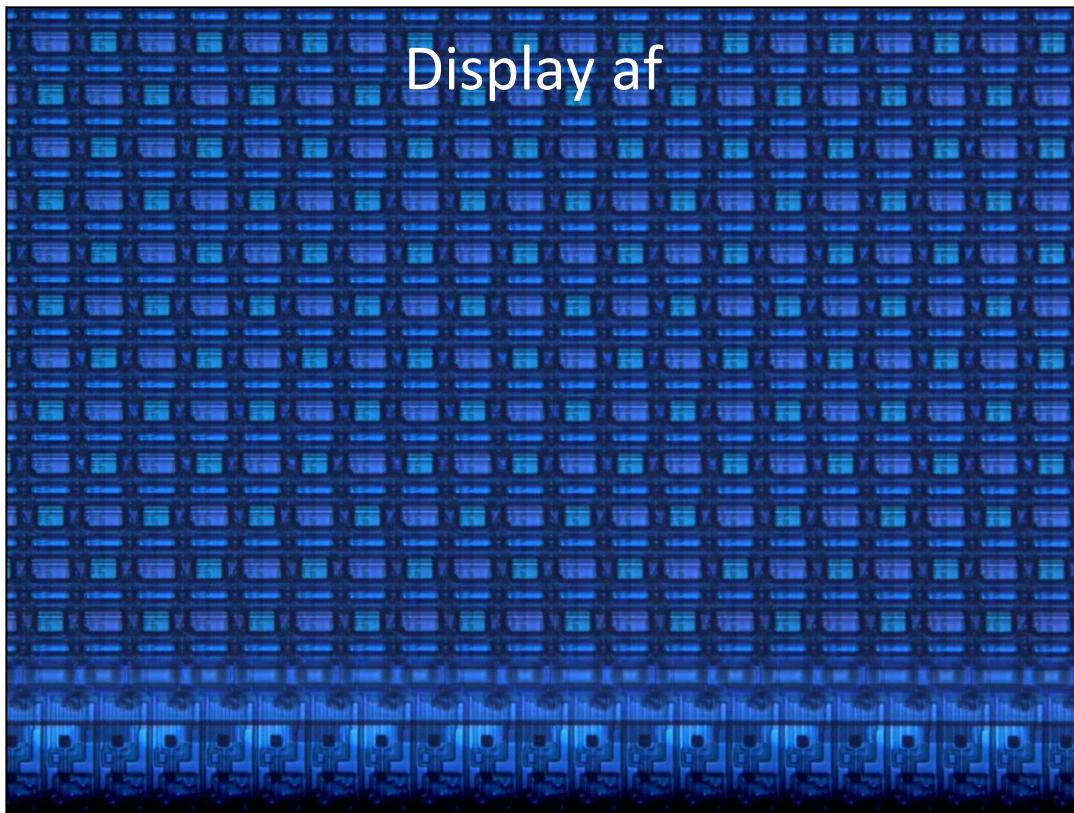
53  
public



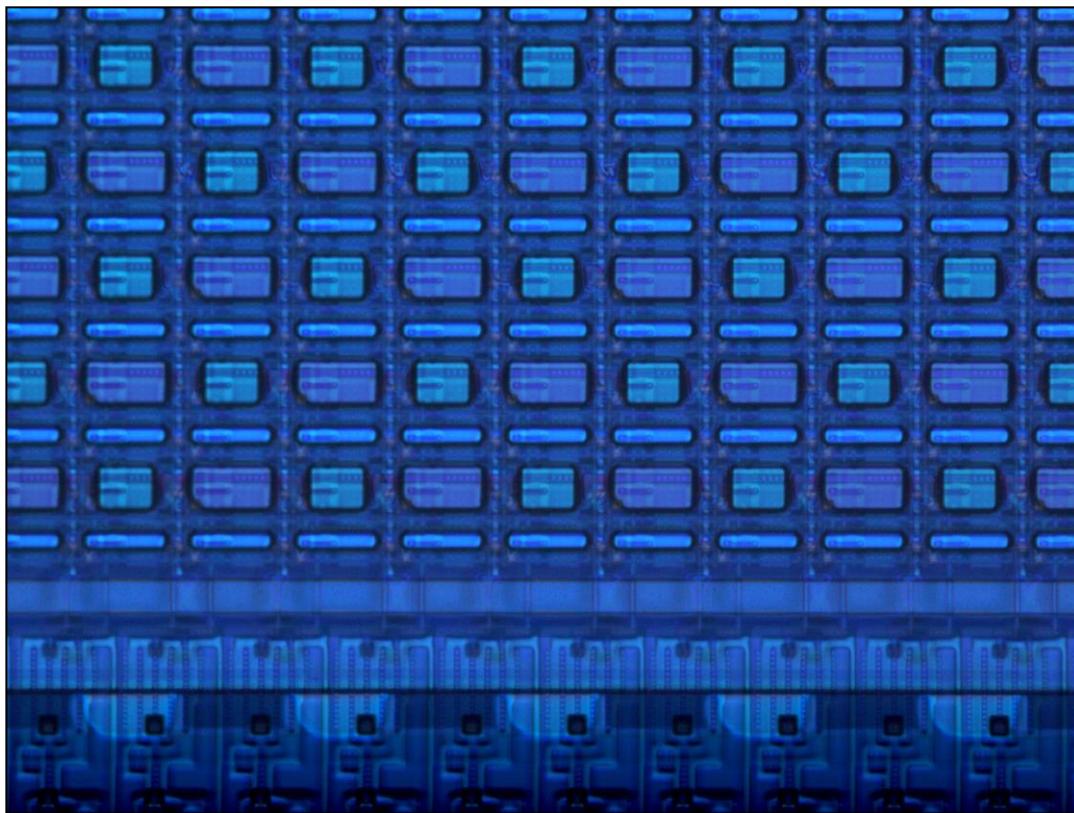
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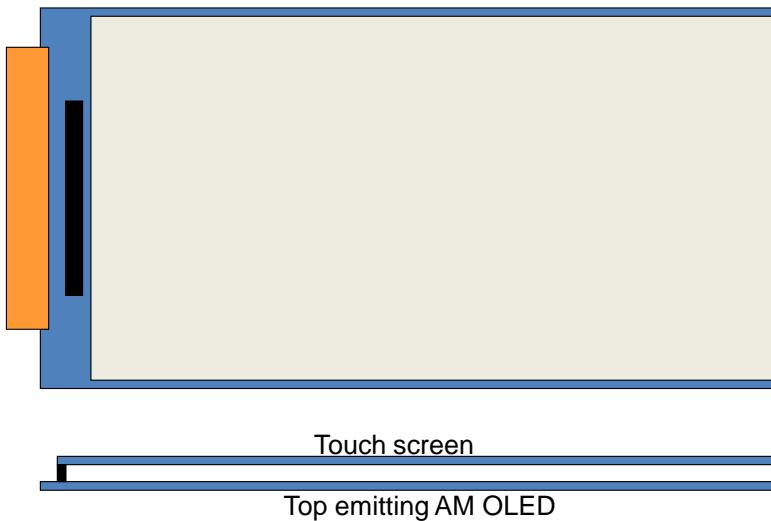


Display af





## overzicht Super AMOLED display

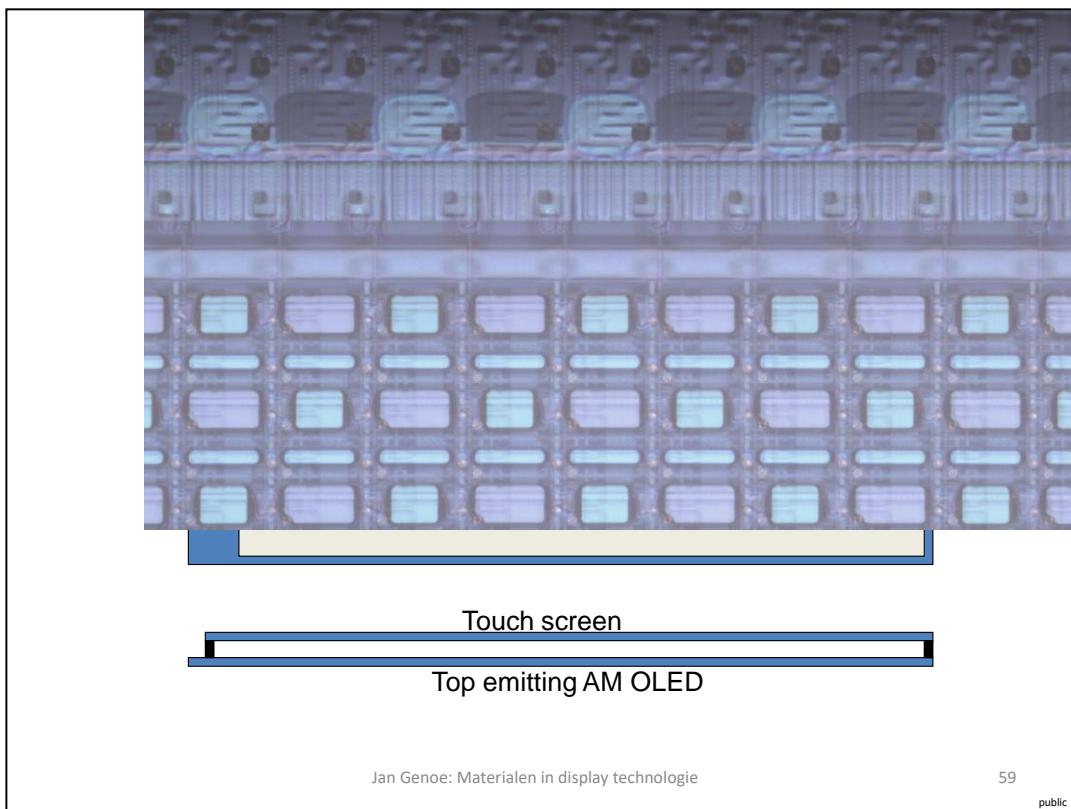


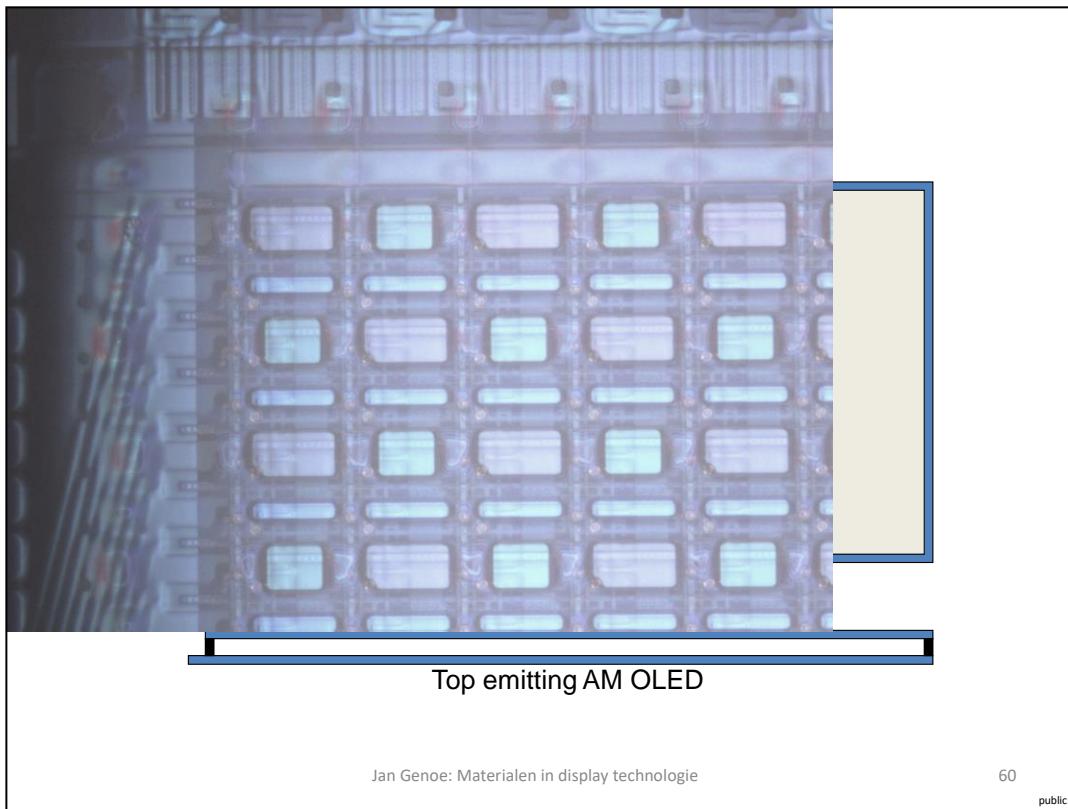
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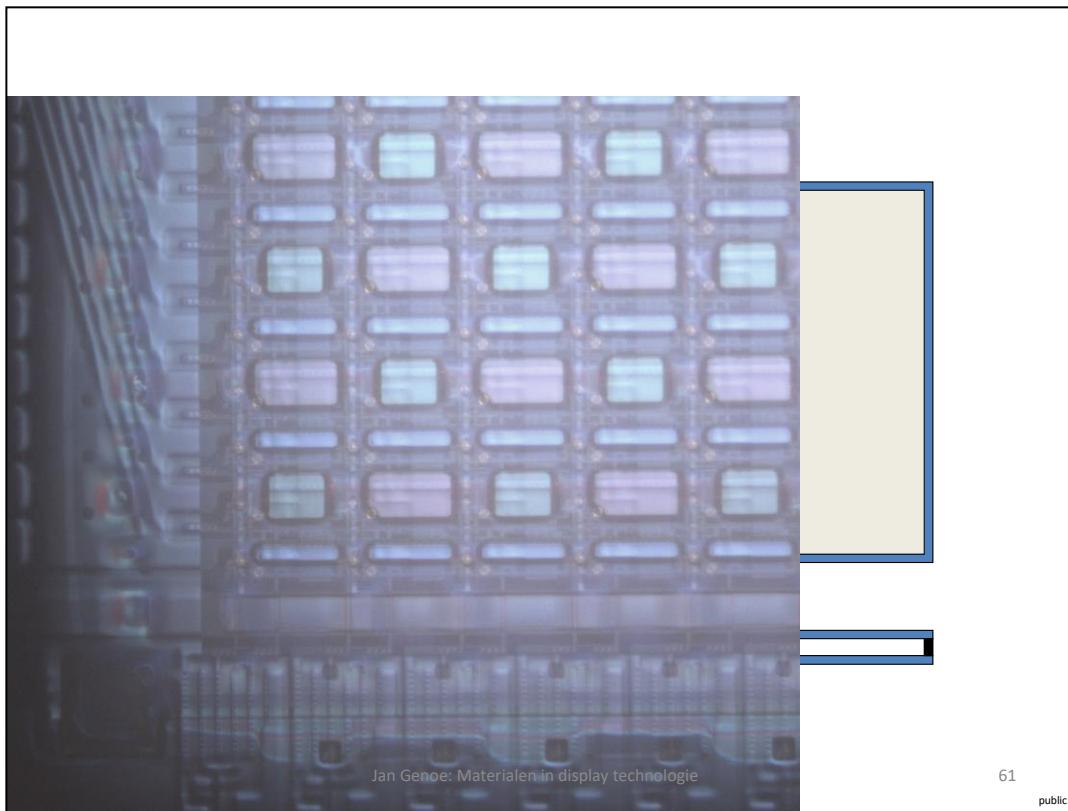


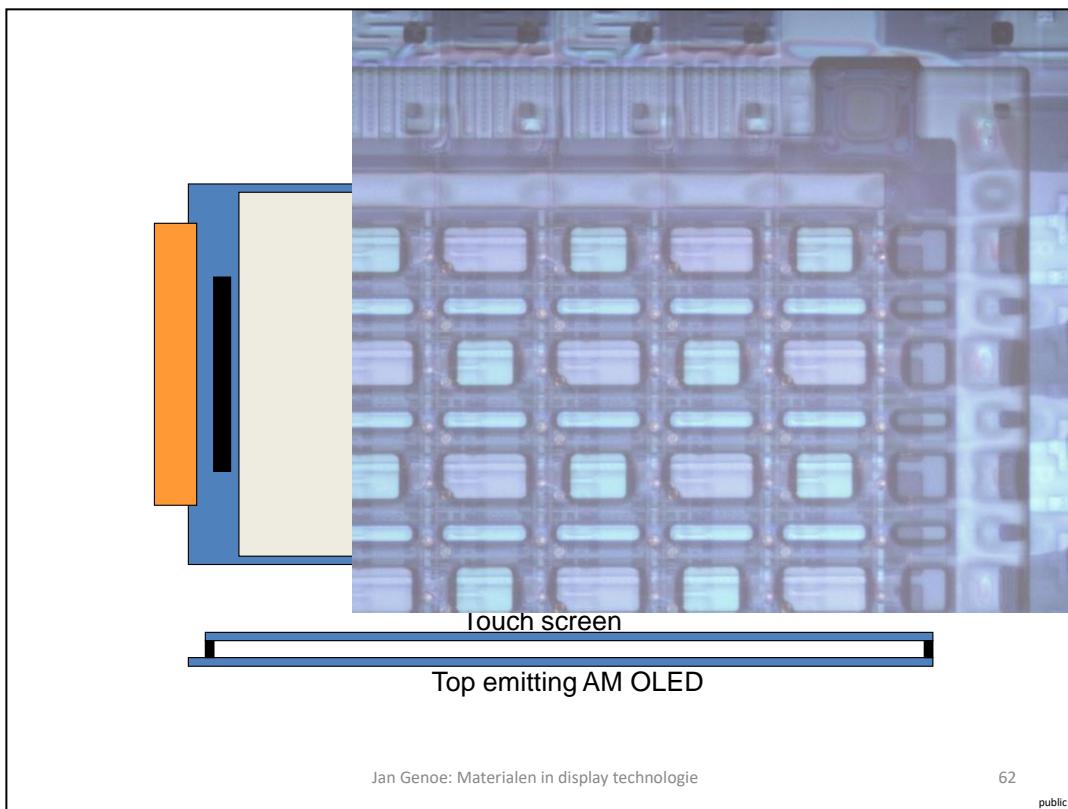


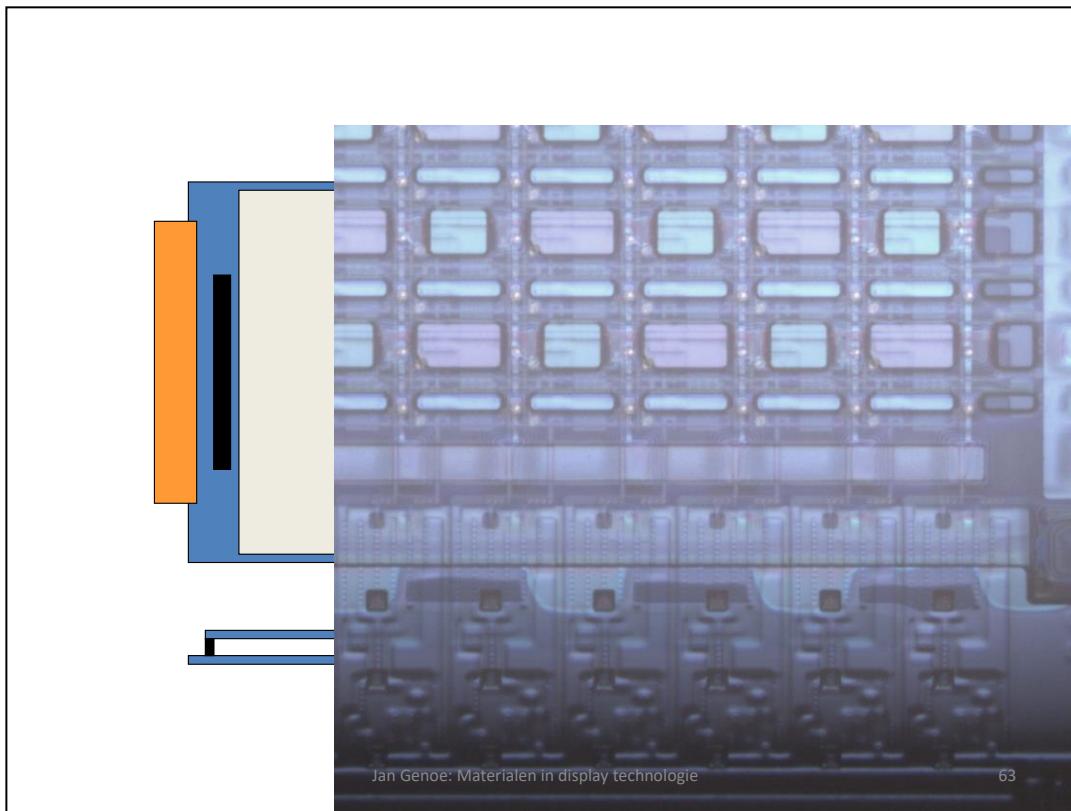
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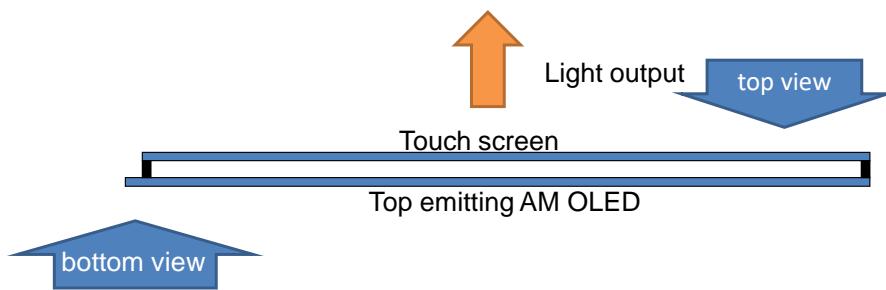
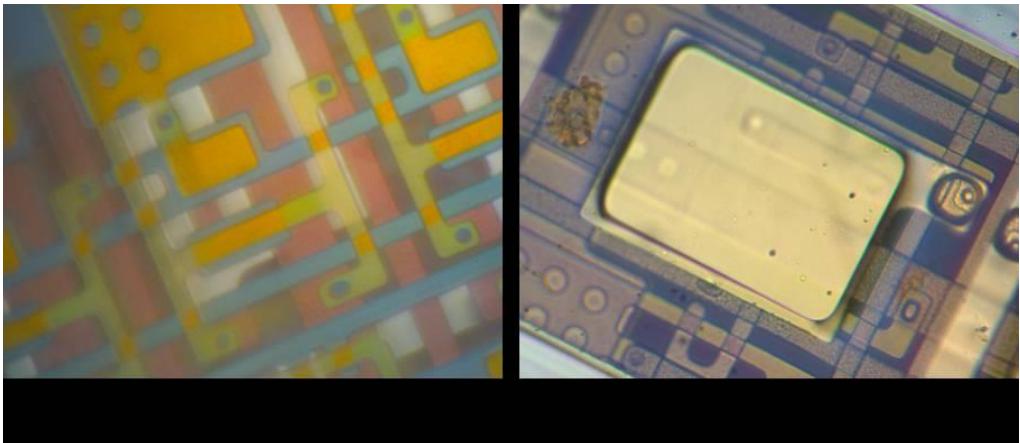
60

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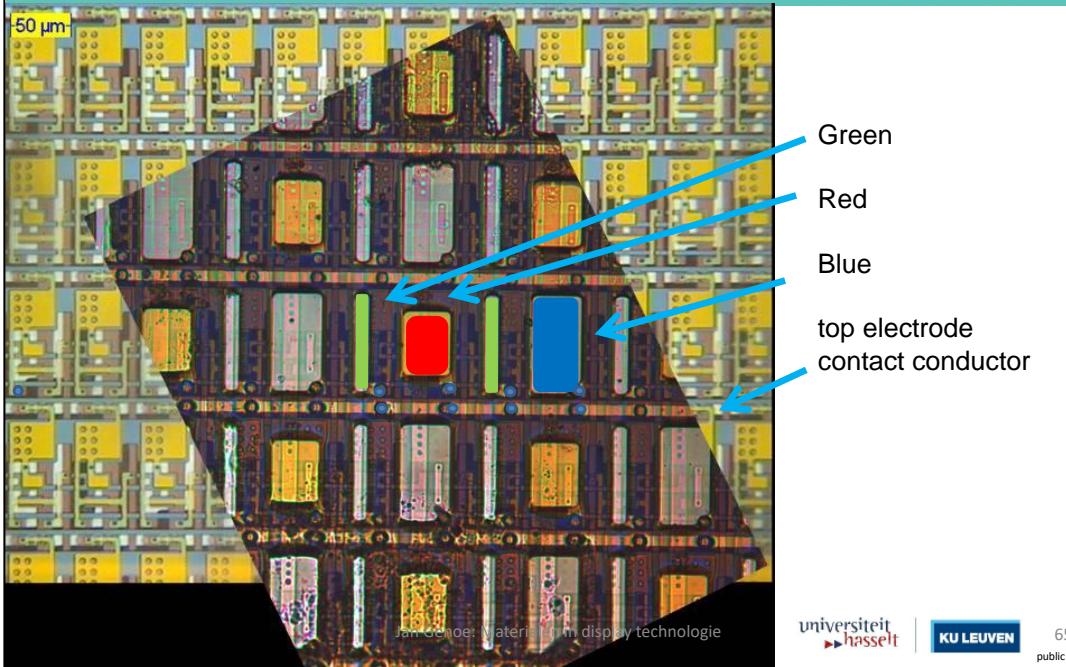
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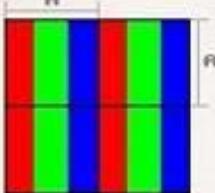
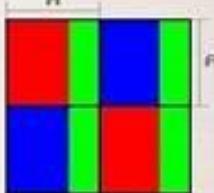
## OLED contacts (bins available)



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## PenTile OLED structure

	RGB Stripe Type	Visual (=PenTile) Type
Resolution	VGA ( 640 x RGB x 480 )	Visual VGA ( 640 x 480 )
Pixel arrangement		
A Pixel	(RGB) Sub Pixel - 3 	(RGB) Sub Pixel - 2 
Sub - Pixel count	921,600 pixel(640 x RGB x 480)	614,000 pixel(320 x RGBG x 480)

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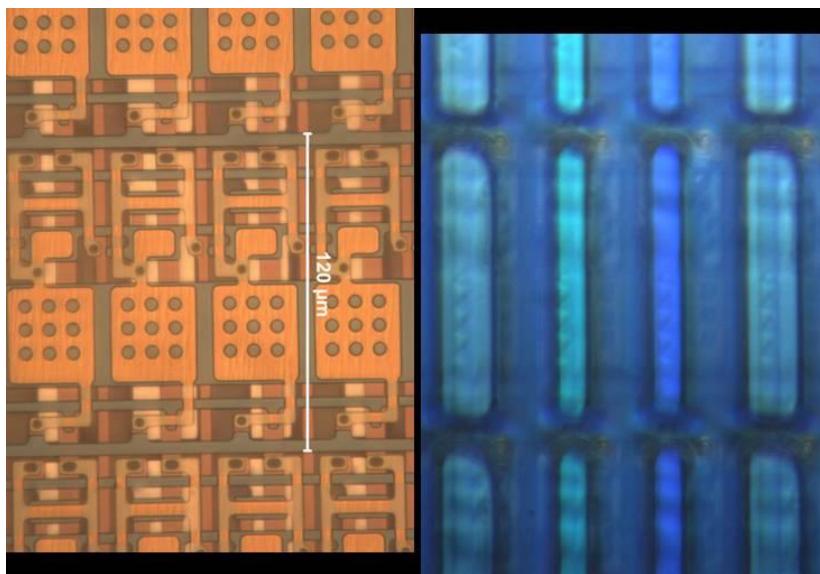
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## Optische microscoop



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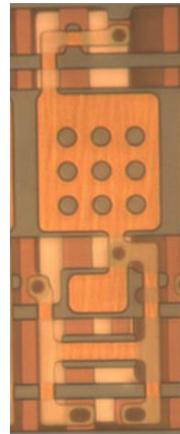
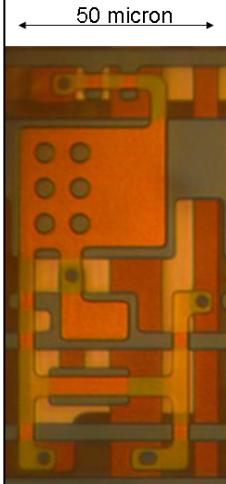
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## Optische microscoop



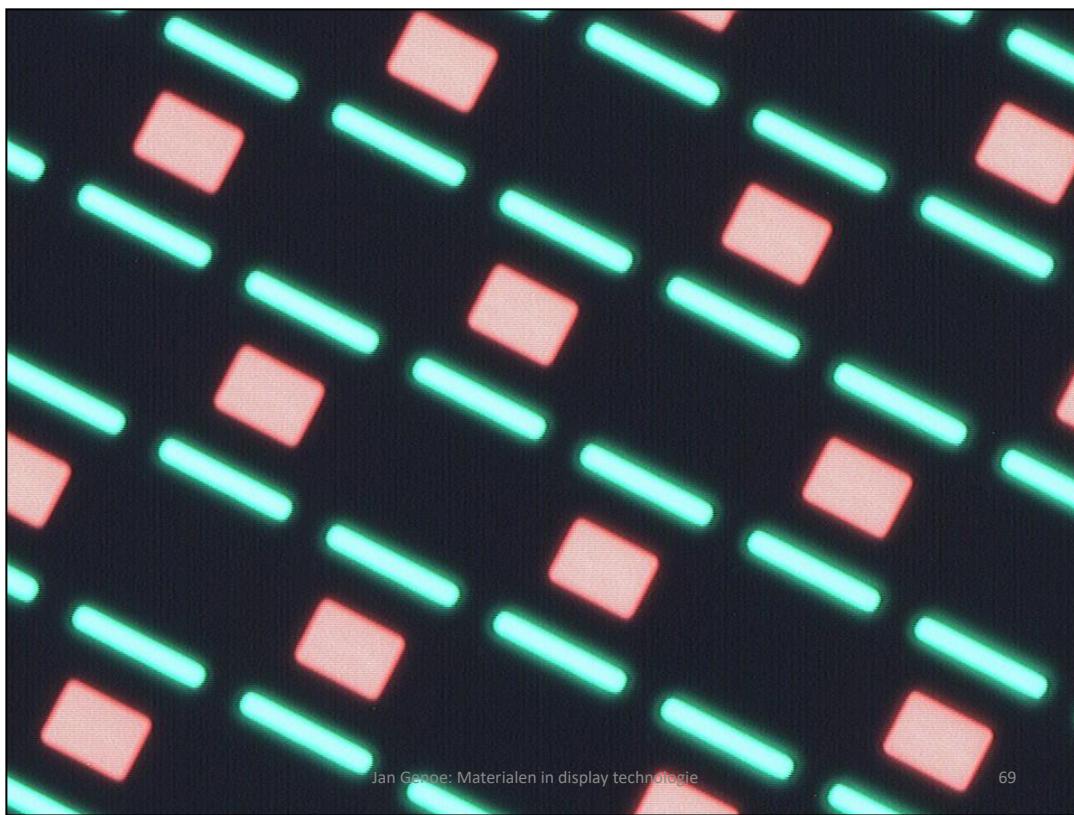
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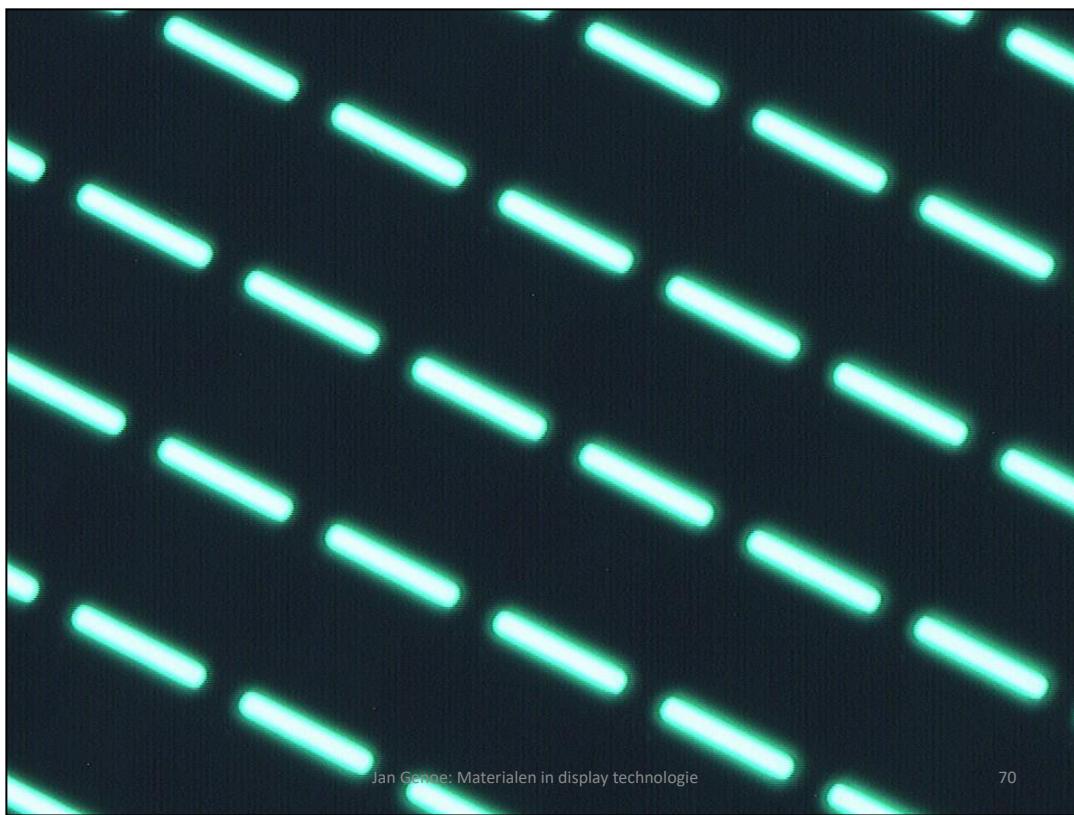
public

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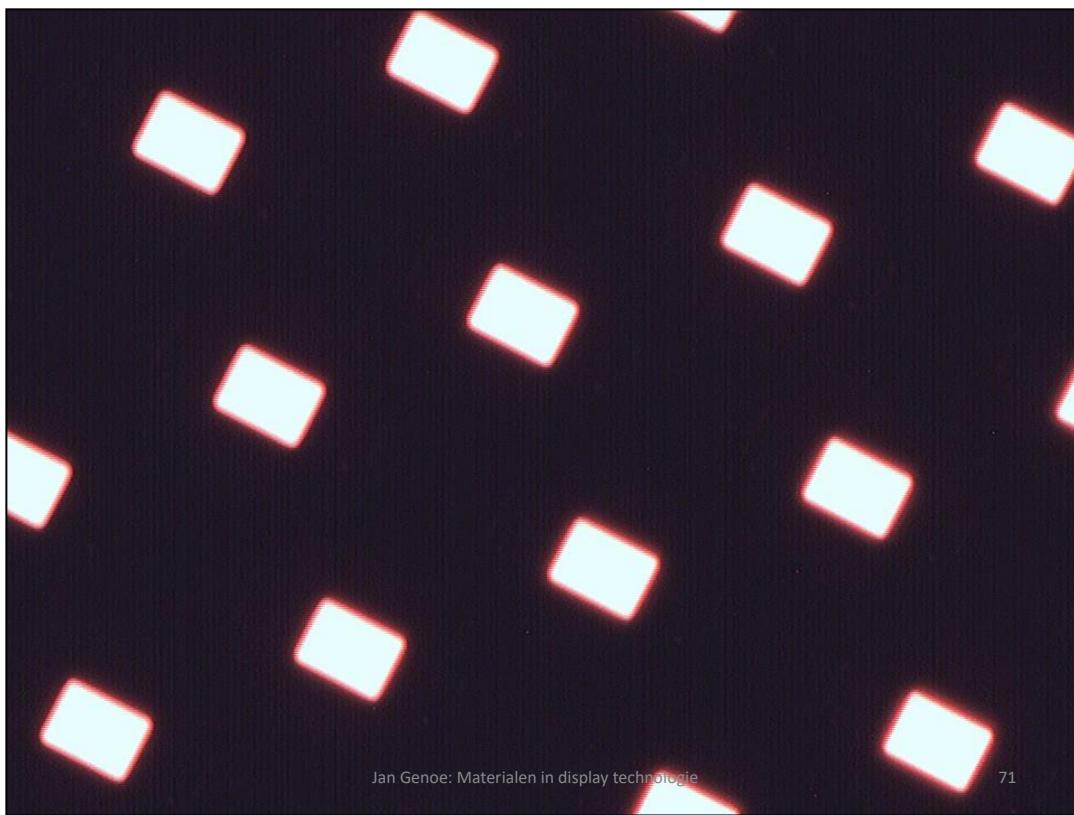
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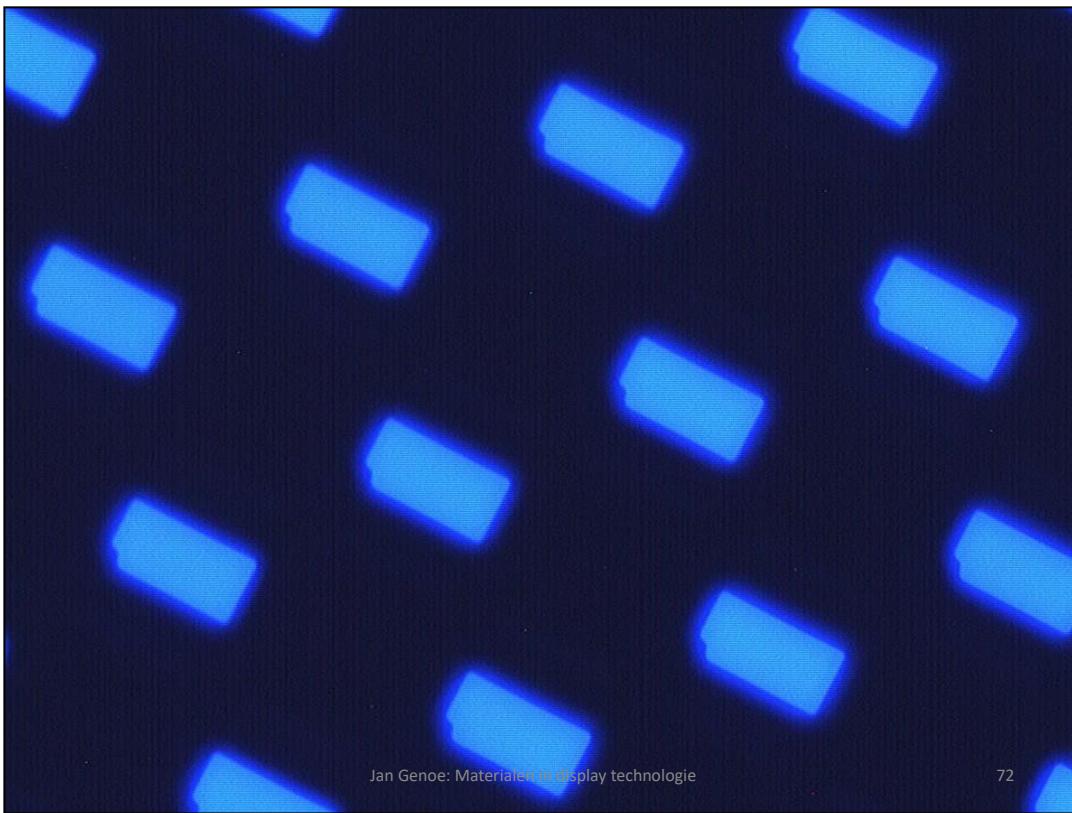
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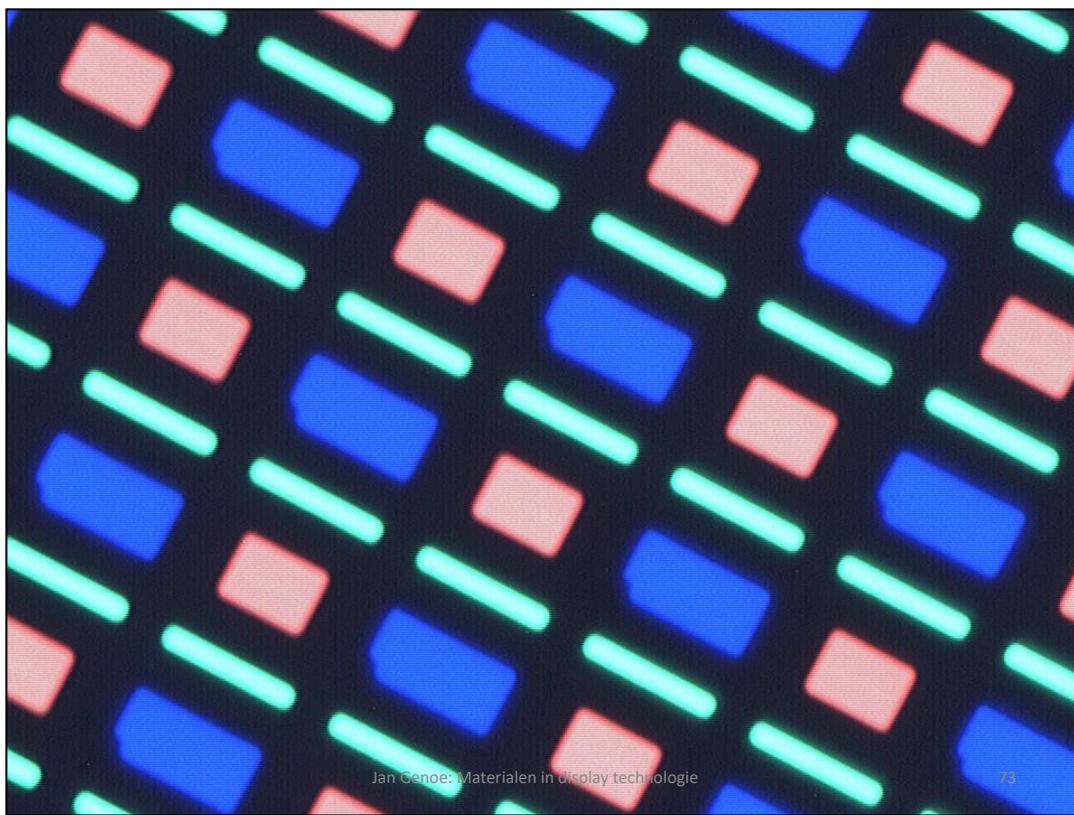
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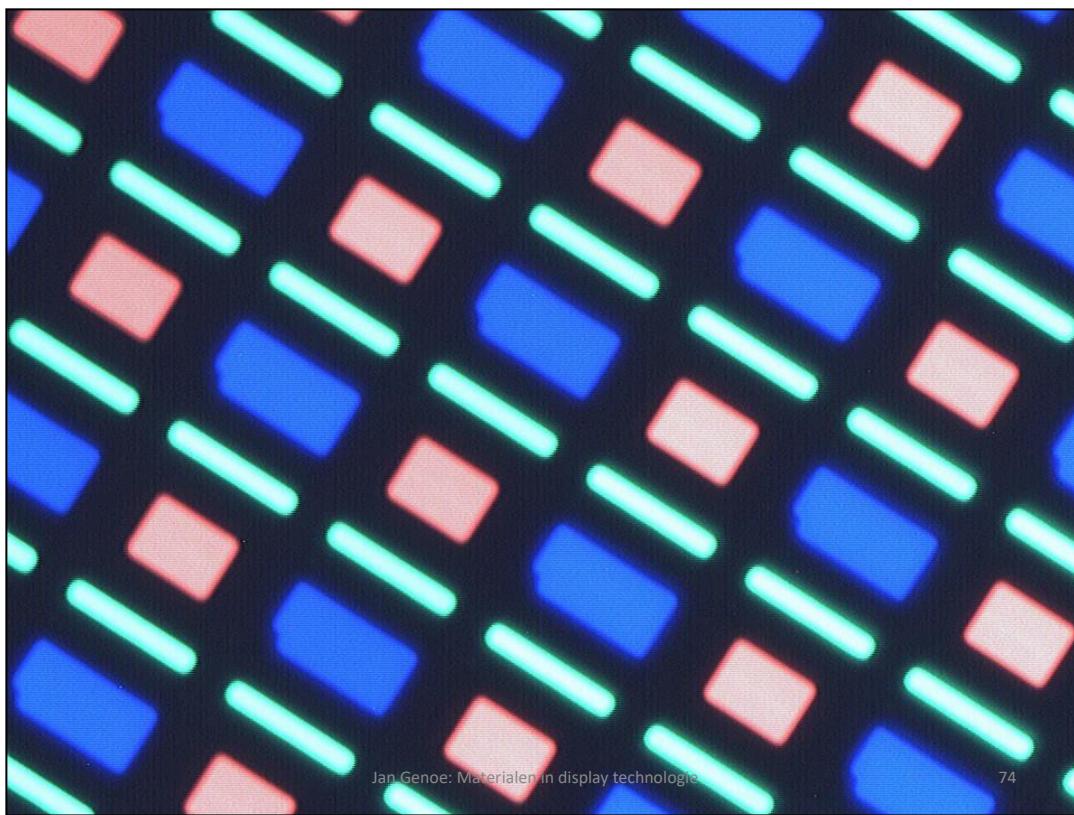
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## HOLST flexible OLEDs

- Een voorbeeld voor signage



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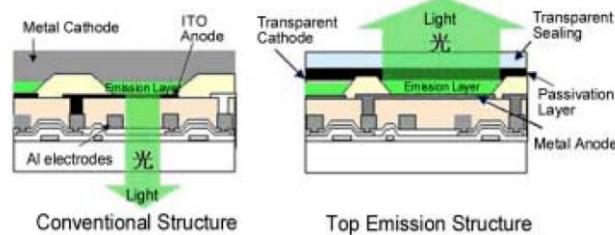
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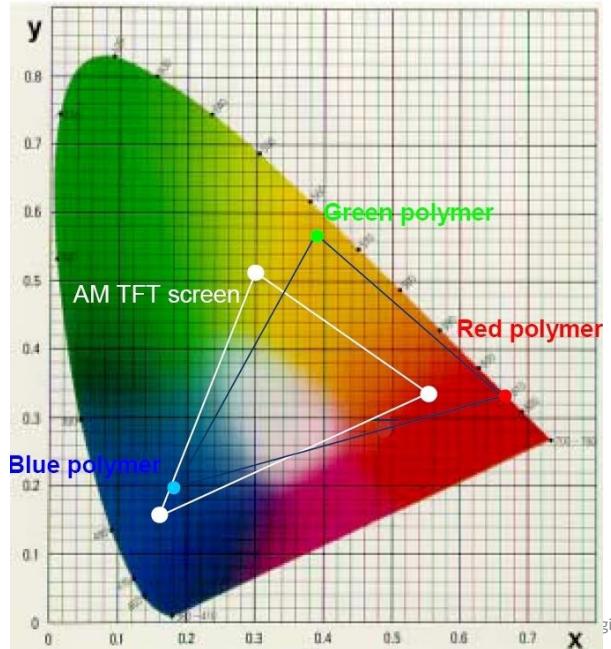
## Van OLED lagen naar displays op glas

- Een controle transistor per pixel moet toegevoegd worden.
- Normaal is de bovenste electrode de spiegelende electrode.
- Transistor neemt een deel van de oppervlakte weg
- Uitdaging: top emitting ....



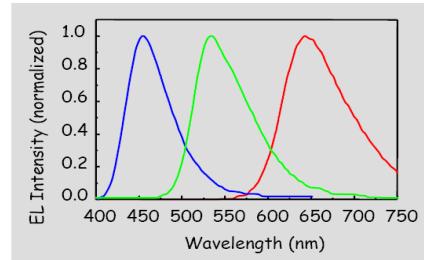
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## Active matrix: LCD versus OLED

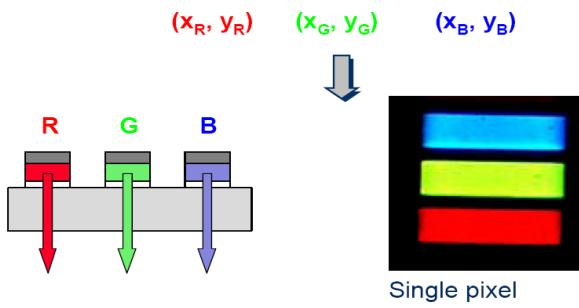


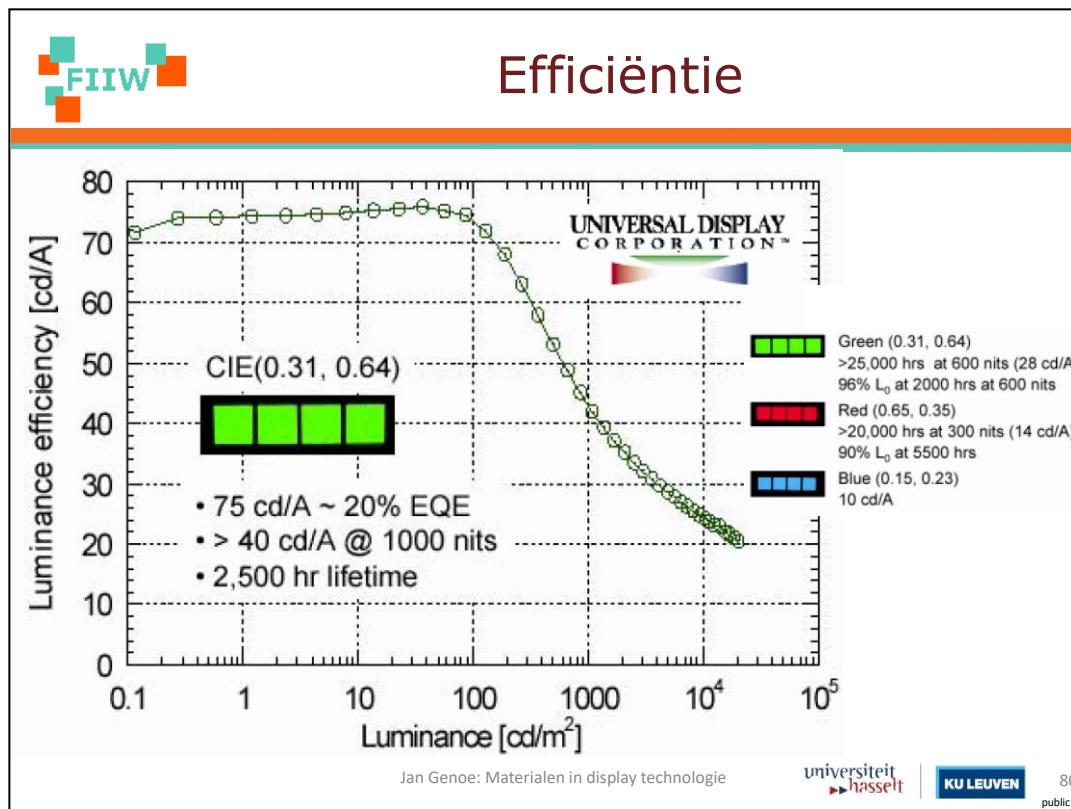


## Goedkope displays: inkjet printen



*Ink Jet printing of R,G,B emissive polymers defines the R,G,B subpixels*







## Overzicht

- Geschiedenis
  - CRT
- Heden
  - LCD
  - DLP
  - OLED displays
- Toekomst
  - E-ink
  - Oprolbare OLED



## Flexibel displays: Harry Potter

### Doel:

- Licht als papier
- Plooibaar
- Onbreekbaar
- Hoge leesbaarheid,  
ook bij veel  
omgevingslicht



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## Evolutie in displays

1965-1975

1975-1985

1985-1995

1995-2005

2005-2015

2015-X

after  
J.P.Morgan



mainframe



Mini  
computer



PC



Notebooks



Mobile  
internet

?

Next

# sold	1M	10M	100M	1B	10B	100B
Volume [m³]	10	1	0.1	0.01	0.001	0.0001
Total [Mm³]	10	10	10	10	10	10

Wat verwachten we van de toekomstige displays (na de tablet):

- 10 keer minder volume
- 10 keer lichter
- Display grootte gelijk of groter dan het toestel

→ future displays: zo dun als folie

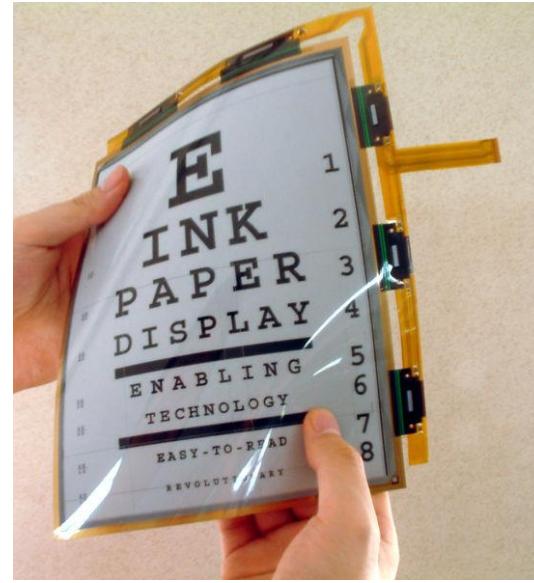
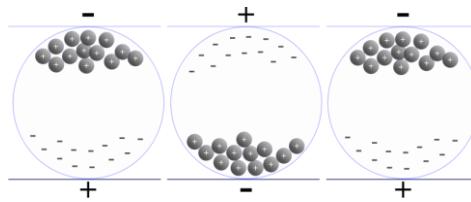
- Ultra dun
- Ultra licht
- Onbreekbaar
- Flexibel, plooibaar of oprolbaar
- Low-power
- Hoge resolutie (> 500 dpi)
- Hoge color quality





## E-ink: zwart-wit

- Spanning laat de E-ink omklappen
- Later geen spanning meer nodig om het display te behouden



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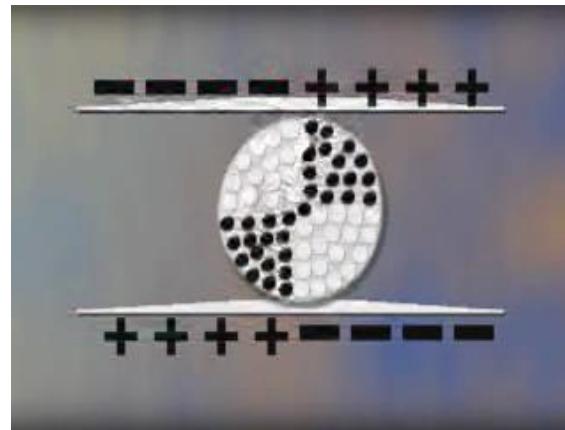
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[1] [http://en.wikipedia.org/wiki/Electronic\\_paper](http://en.wikipedia.org/wiki/Electronic_paper)



## Spanningen aanleggen



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## Plastic logic display

# Plastic Logic

## Why Flexible Displays?

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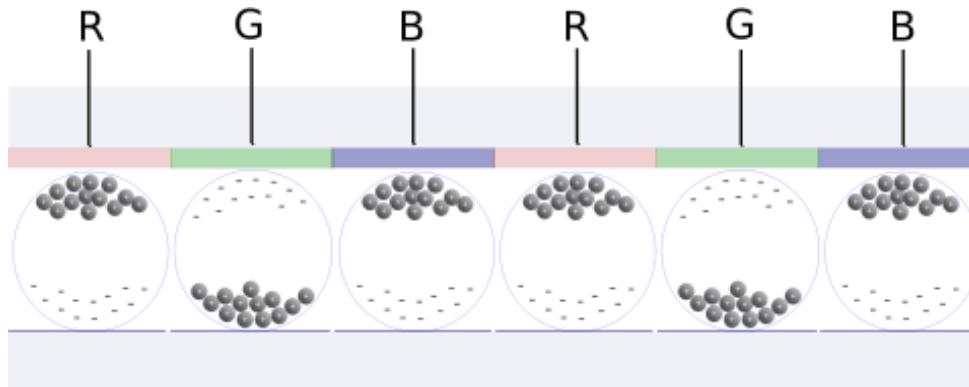
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## E-ink met kleurenfilter

- Toevoegen van filters geeft een kleurendisplay



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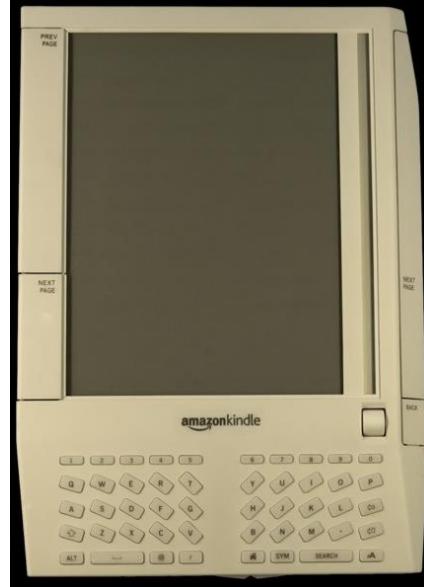
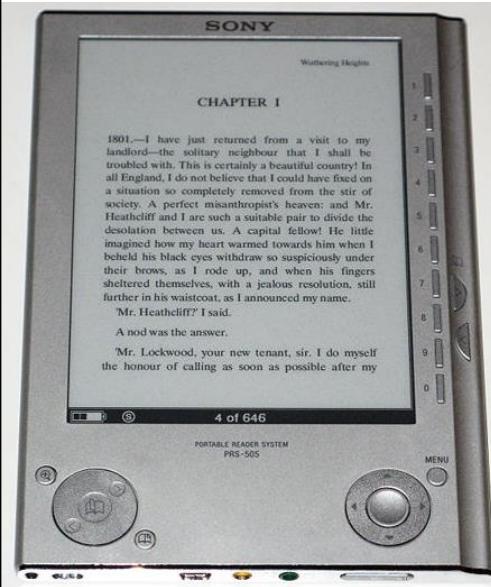
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Hierdoor verlies je wel 1/3 van het gereflecteerde licht. Hierdoor lijkt een e-ink display met kleurenfilters altijd een beetje flets. Heel anders dan een zwart-wit display, wat een heel goed contrast geeft.



## Sony en Amazon e-book reader



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## Oprolbaar E-ink display



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[1] [www.polymervision.com](http://www.polymervision.com)



## Oprolbaar E-ink display

READiUS.  
by  
Polymer Vision



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[1] [www.polymervision.com](http://www.polymervision.com)



## Oprolbaar E-ink display



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[1] [www.polymervision.com](http://www.polymervision.com)



## Overzicht

- Geschiedenis
  - CRT
- Heden
  - LCD
  - DLP
- Toekomst
  - E-ink
  - OLED displays
  - Oprolbare OLED : de uitdaging



## Oprolbare OLED de uitdaging



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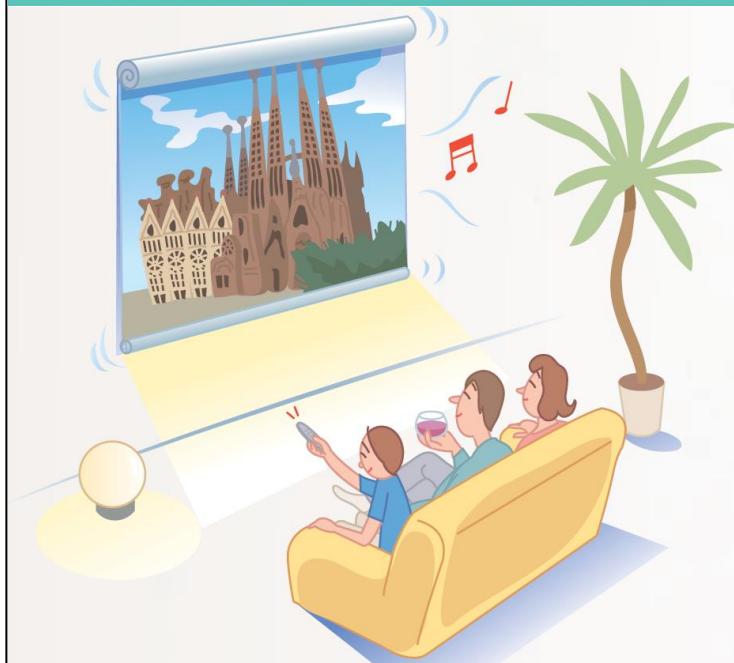
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## Toekomstvisie (Sony)



Een grote TV

Maar geen groot  
zwart vlak als hij af  
staat

[1] Sony, Sideview 62, 2010



## onbreekbaar display?



- Gebroken displays zijn de belangrijkste reden van failure van mobile devices.
- Een flexibele display technologie is de sleutel naar een echte onbreekbaar scherm

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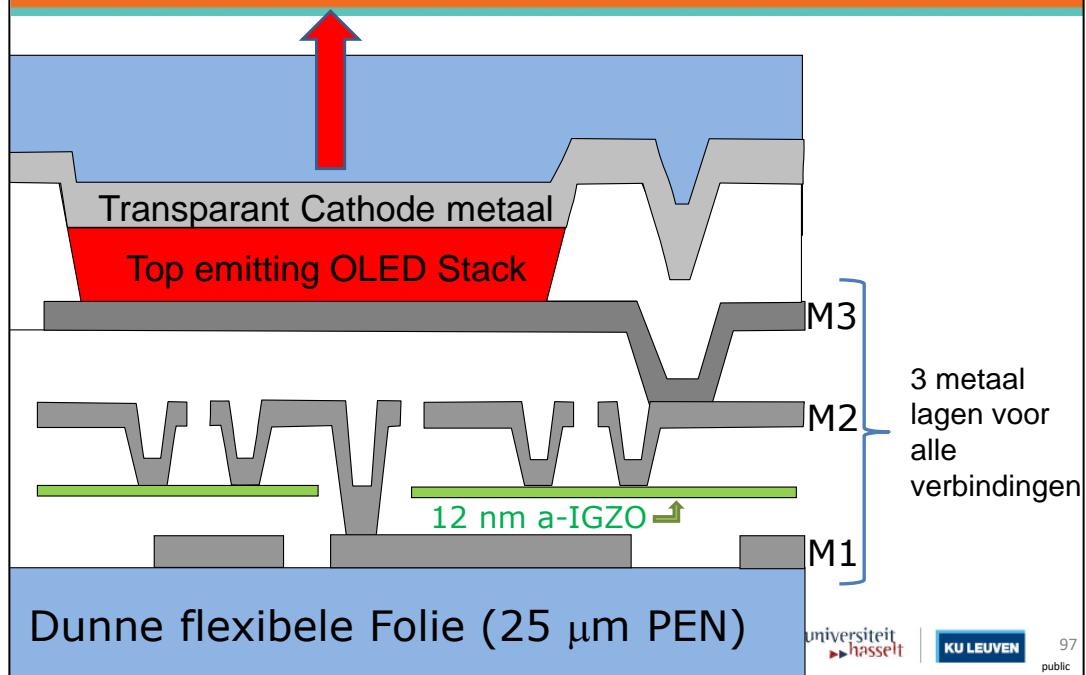
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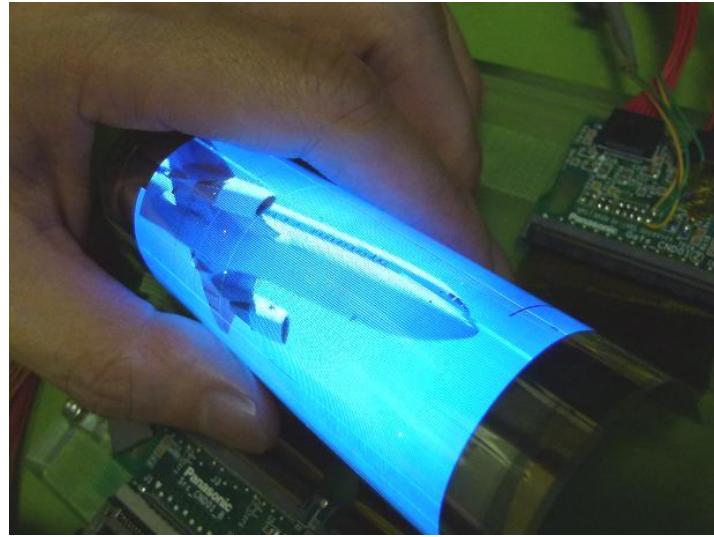
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## AMOLED displays on foil





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## Plooibaar kleuren display@SID 2013



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- [1] Yusuke Fukui, M. Shibata, Y. Tanaka, K. Okumoto, K. Morita, K. Otake, A. K. Tripathi, B. van der Putten, Jan-Laurens van der Steen, K. Tempelaars, L. van Leuken, F. Li, I. Yakimets, G. Gelinck, K. Myny, S. Smout, M. Willegems, S. Schols, S. Steudel, J. Genoe, and P. Heremans, "Full Color Flexible Top-emission AMOLED Display on Polyethylene Naphthalate (PEN) Foil with Metal Oxide TFTs Backplane," in SID Symp. Dig. Tech. Papers 2013, Vancouver, Canada, 2013, vol. 44, pp. 203–206.



# Touchscreens

## Overzicht:

- Resistive touch screens
- Capacitive touch screens
  - Self capacitance
  - Mutual capacitance
- Optical touch screens

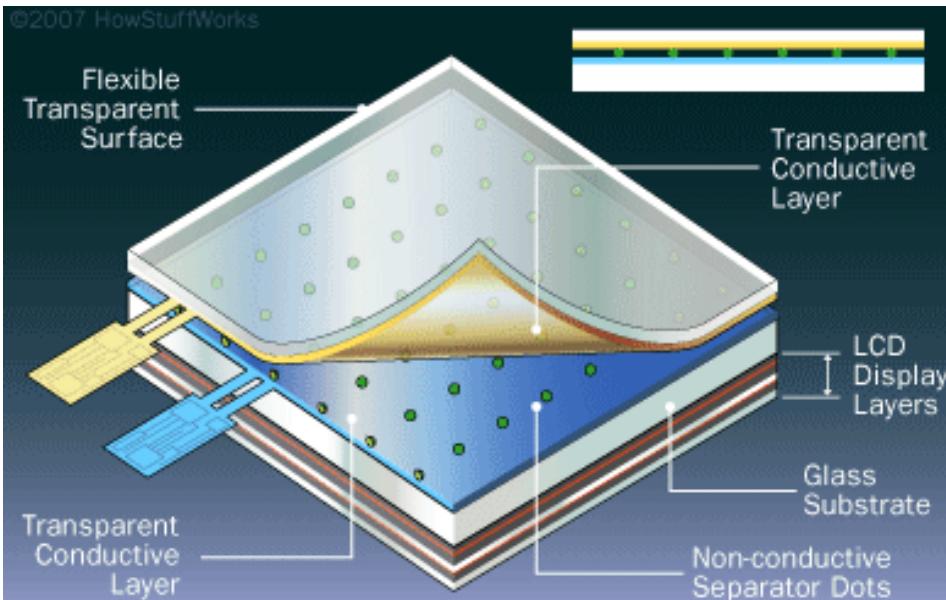
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[1] How stuff works



## Resistive Touchscreens



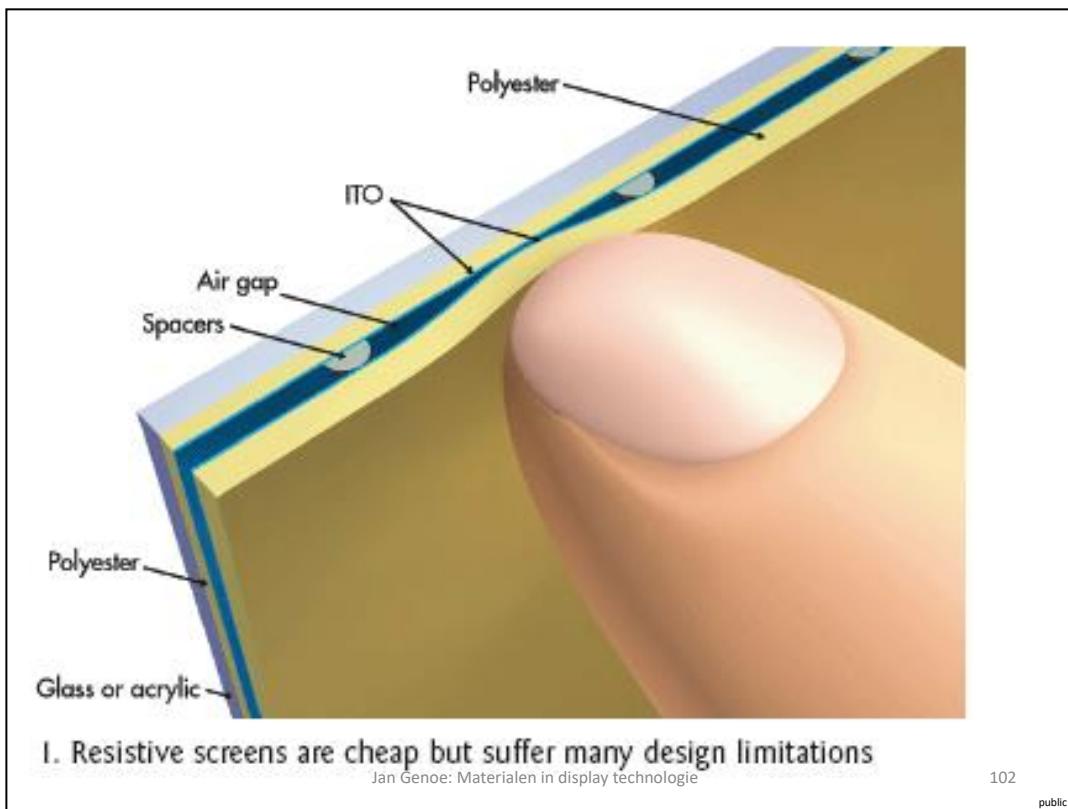
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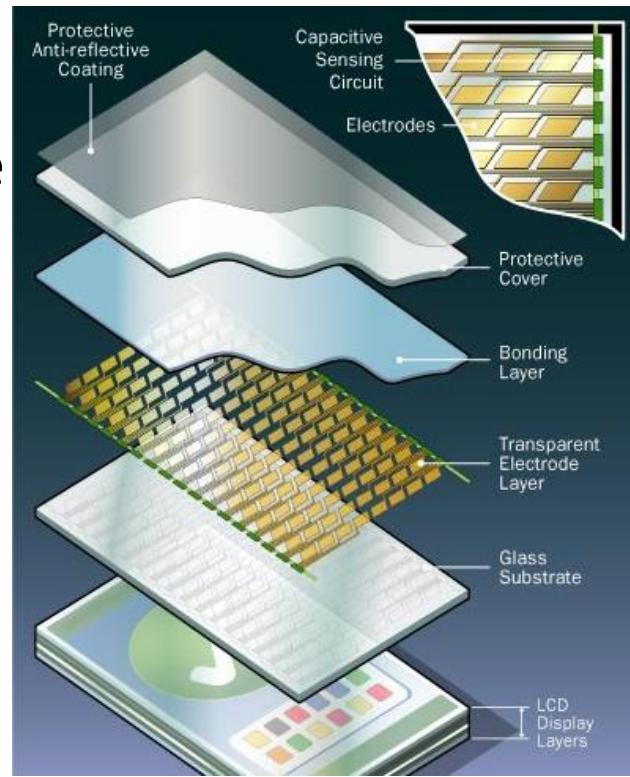
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101

[1] How stuff works



[1] How stuff works

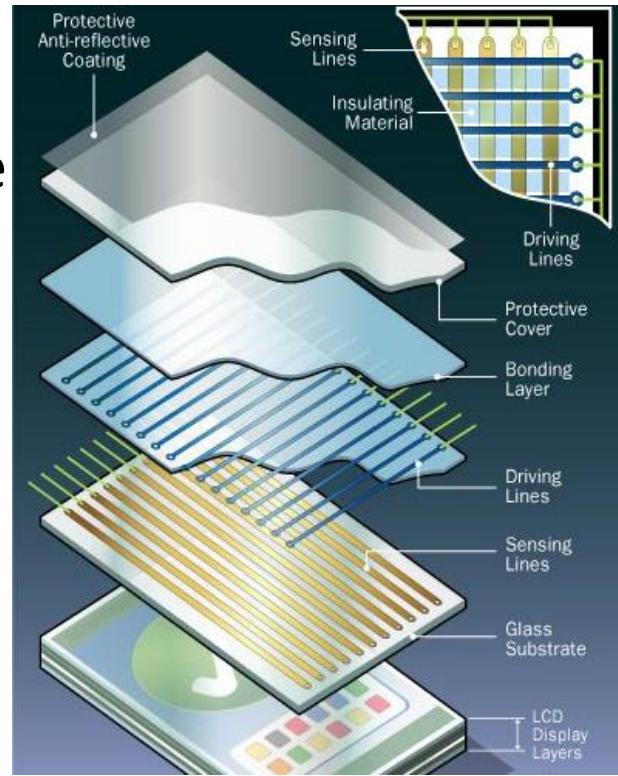
# Self capacitance



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# Mutual capacitance



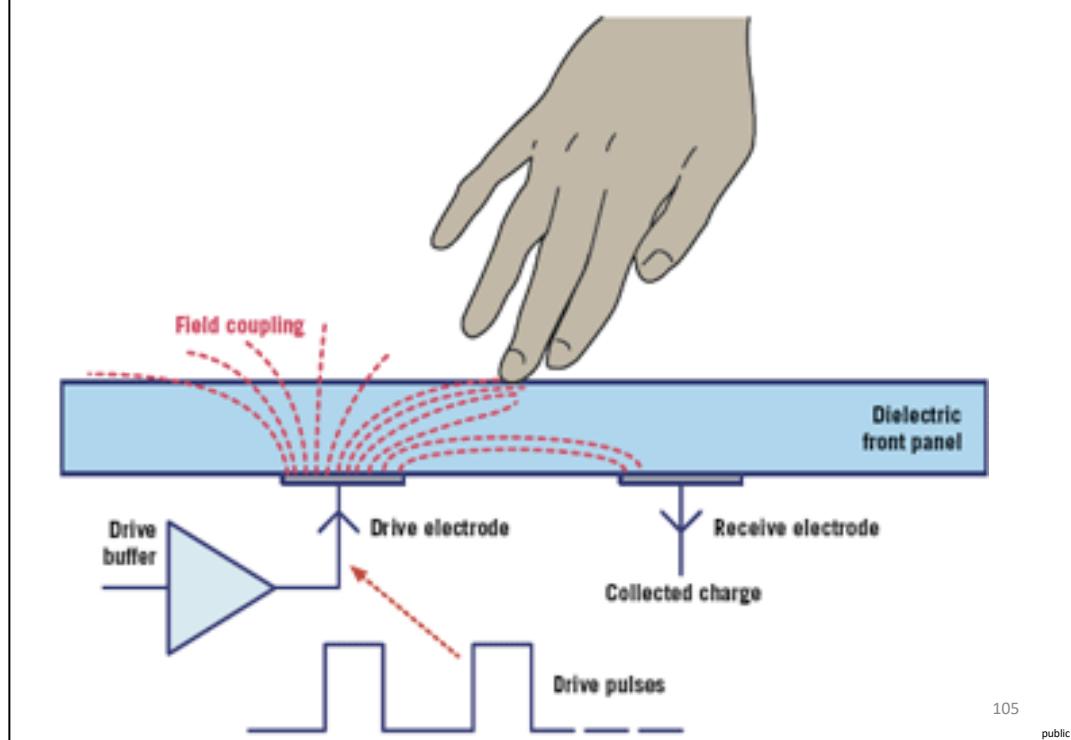
104

public

[1] How stuff works

[2] M. Miyamoto, M. Hamaguchi, and A. Nagao, "A 143 81 Mutual-Capacitance Touch-Sensing Analog Front-End With Parallel Drive and Differential Sensing Architecture," *IEEE Journal of Solid-State Circuits*, vol. 50, no. 1, pp. 335–343, Jan. 2015.

### Projected capacitive touchscreen.



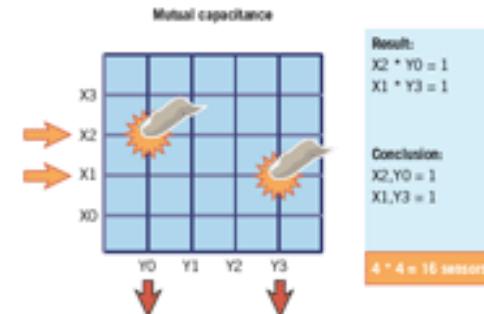
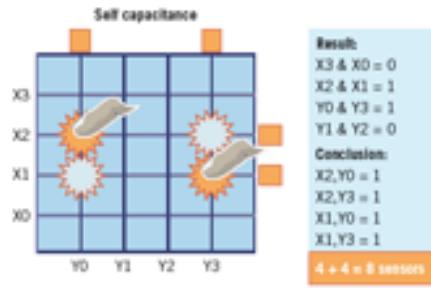
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# Capacitive multi-touch

Mutual vs. self capacitance.

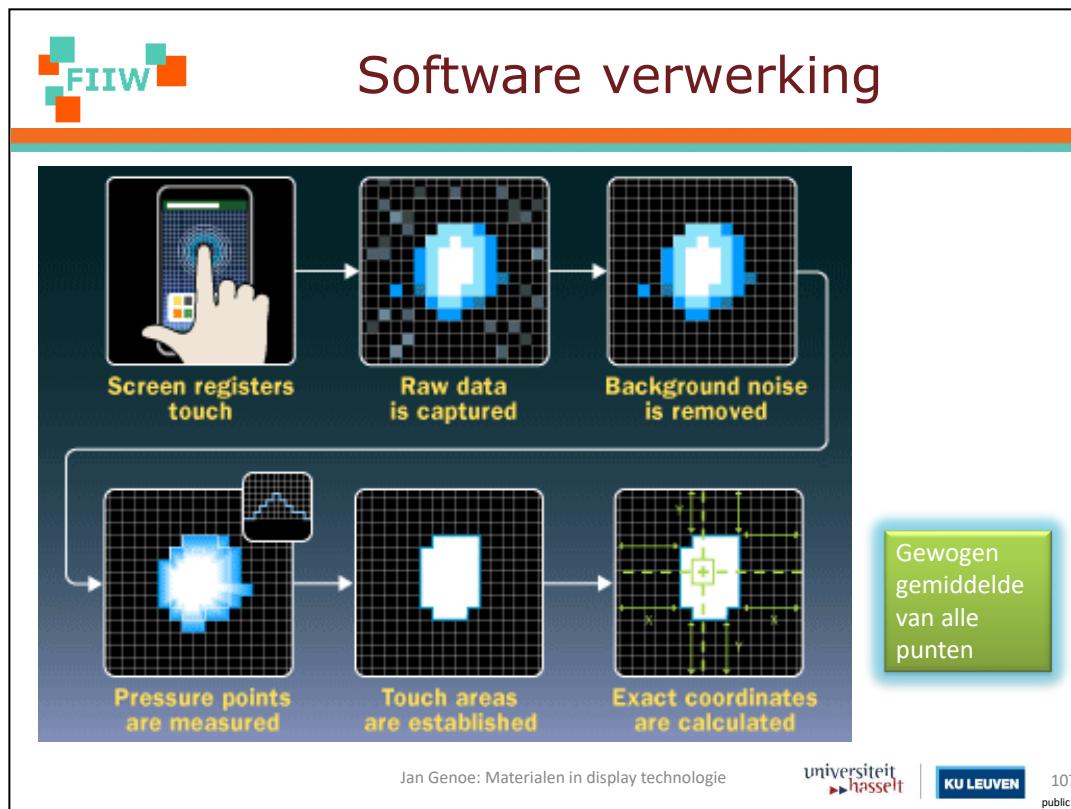


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## [1] How stuff works

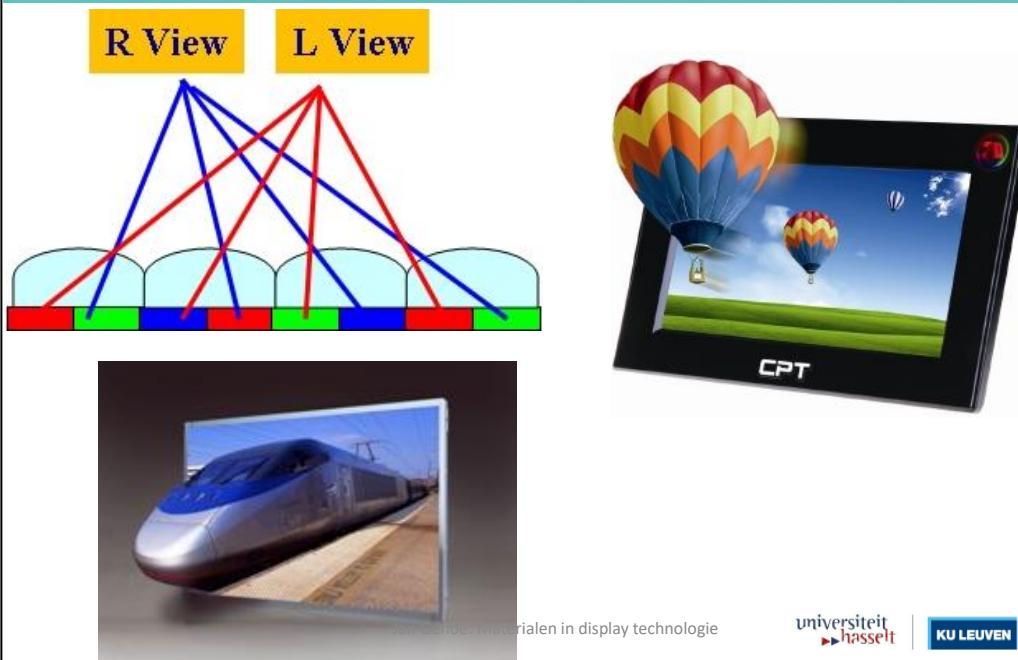


## 3D displays overzicht

- 3D Displays zonder bril
  - Displays met  $\mu$ -lenzen
  - Holographische displays
- 3D Displays met bril
  - Polarisatie filter
  - Kleurenfilter
  - Schakelen (active shutter)



## 3D displays met $\mu$ -lenzen



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[1] <http://www.cptt.com.tw>



## Large scale holographic displays



Fragment from: Life in 2025 – imec's vision on future technologies in daily life

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## 3D display met bril

- Polarisatie filter
- Kleurenfilter
- Schakelen (active shutter)



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[1] [http://en.wikipedia.org/wiki/Active\\_shutter\\_3D\\_system](http://en.wikipedia.org/wiki/Active_shutter_3D_system)