FACULTY OF ENGINEERING
AND ARCHITECTURE

ELECTRONICS AND INFORMATION SYSTEMS DEPARTMENT
LIQUID CRYSTALS AND PHOTONICS RESEARCH GROUP

LIQUID CRYSTALS AND LIGHT EMITTING MATERIALS FOR PHOTONIC APPLICATIONS

Kristiaan Neyts April 2018 Lecture series at WAT in Warsaw

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nb-photonics
Center for Nano- and Biophotonics
Ghent University

Liquid Crystals and Photonics

OVERVIEW

Display applications (6h)

The human eye
Display characteristics
Direct drive and active matrix
LCD backlight
Projection displays
OLEDs
Spatial light modulator

OLED DISPLAYS

Light emitting thin film, excellent dark state
for smart phones (Samsung) and TVs (LG)

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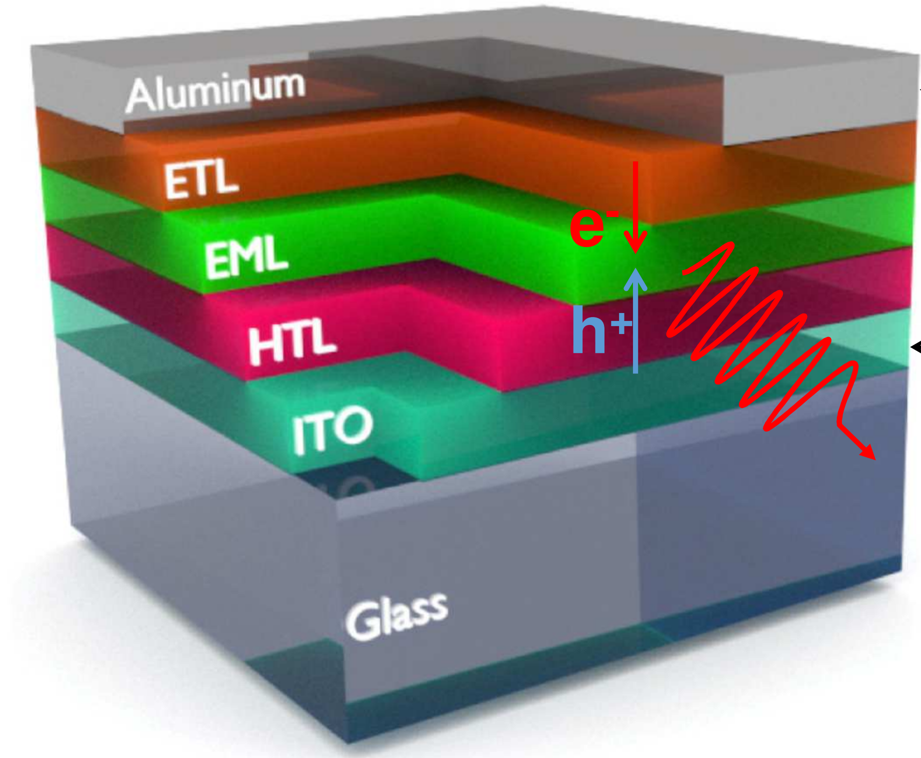
OLED DISPLAYS

basic operation: Organic Light Emitting Diode



← reflective electrode (-)
ETL: electron transport layer
EML: emissive layer
HTL: hole transport layer
← transparent electrode (anode +)

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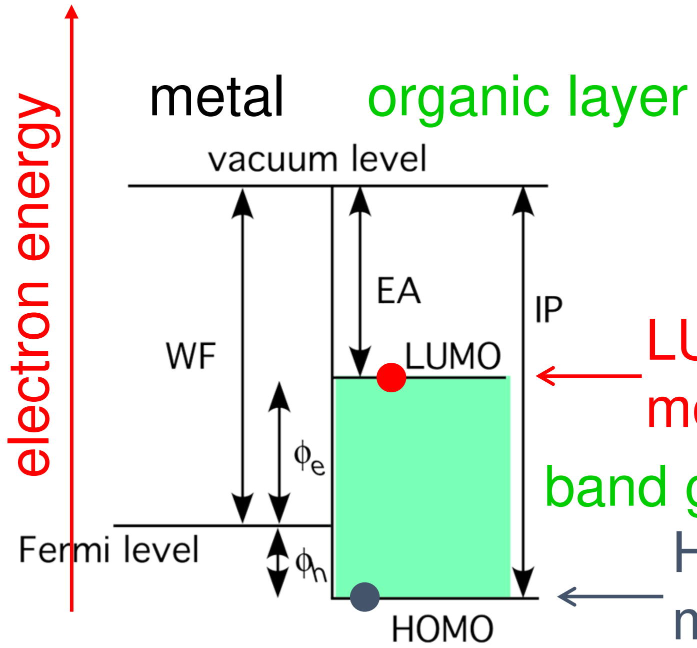
OLED DISPLAYS

Organic materials

electrons in molecular orbitals (e^- band diagram)



EA: electron affinity

IP: ionization potential

LUMO: lowest unoccupied molecular orbital: e^-

band gap

HOMO: highest occupied molecular orbital: h^+

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OLED DISPLAYS

Organic stack with a voltage applied

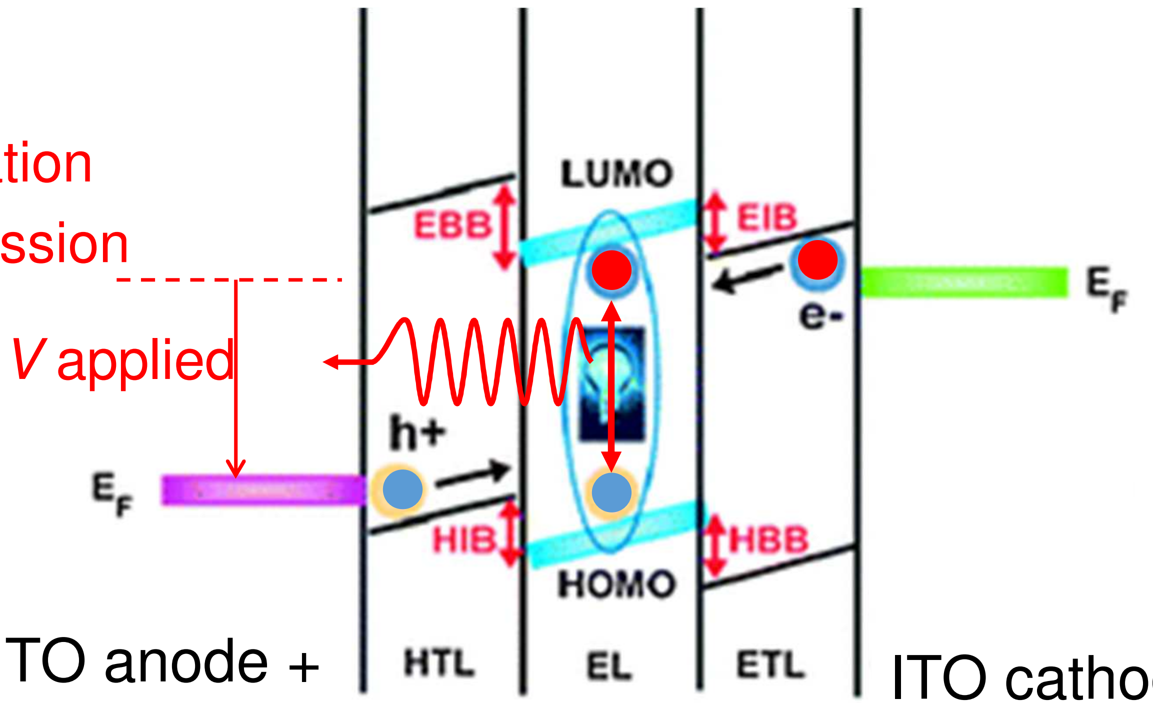
electron energy band diagram

e^- and h^+ injection (IB) and blocking (BB) barriers

exciton

recombination

+ light emission



ITO anode +

ITO cathode -

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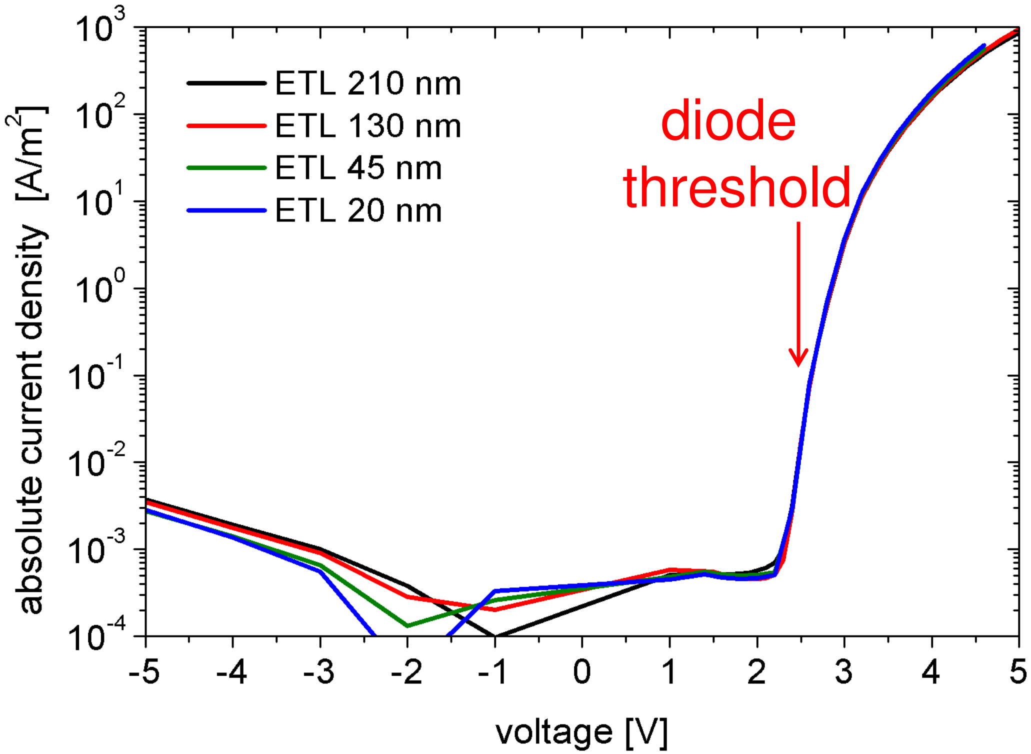
OLED DISPLAYS

OLED current voltage characteristic (*I*-*V*)

diode: only current for positive bias *V*>0



OLED DISPLAYS

OLED efficiency parameters

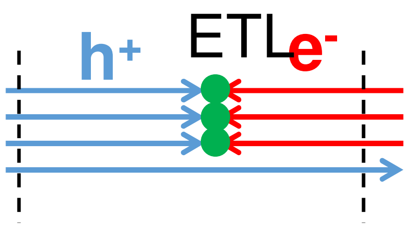
charge balance efficiency: η_{cb}

if holes are not stopped by the ETL,

they can move to the cathode without exciton creation

η_{cb} = # excitons created / # charges crossing the ETL

example: anode



cathode

η_{cb} = 3 / 4

with a Hole Blocking Layer: η_{cb} ~ 1

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OLED DISPLAYS

OLED efficiency parameters

efficiency η_{st} fraction of states that allow emission

electron and hole form an exciton

molecule in excited state: ¼ singlet, ¾ triplet state

↓ emission allowed

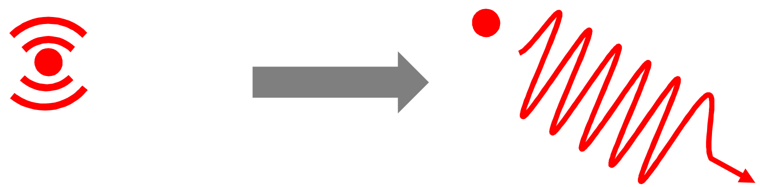
↓ emission spin-forbidden

Pt or Ir: spin-orbit coupling

η_{st} = 25% or 100%

quantummechanical transition

from exciton to photon



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OLED DISPLAYS

OLED efficiency parameters

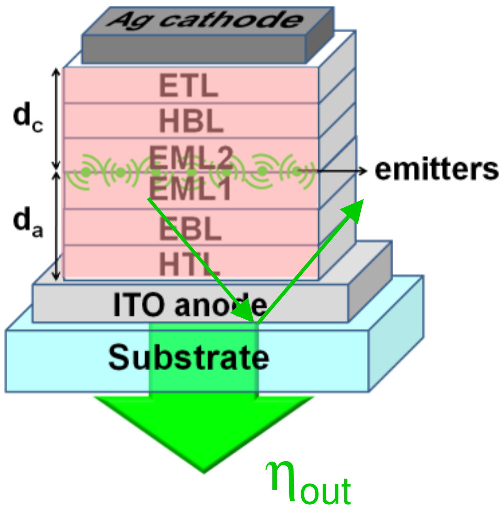
outcoupling efficiency: η_{out}

some photons are trapped: total internal reflection (high n)

some photons are absorbed by the Al or ITO

some photons are absorbed by the organic layers

η_{out} = emission into air / total generation of photons



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OLED MATERIALS AND DEPOSTION

Substrate and anode

- glass with ITO, flat or curved

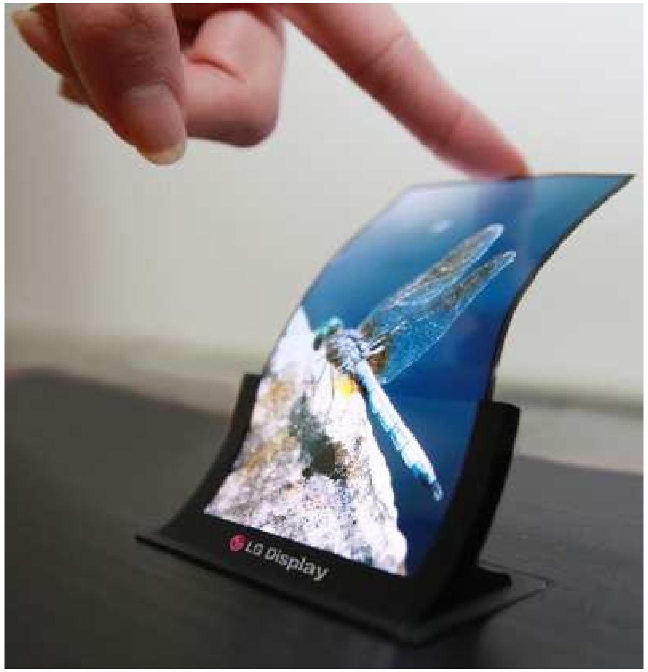
barrier for humidity and oxygen, high conductivity

- polymer foil with PEDOT-PSS

for flexible OLEDs

buffer for humidity and oxygen?

low conductivity of PEDOT-PSS



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OLED MATERIALS AND DEPOSITION

organic layers by thermal evaporation

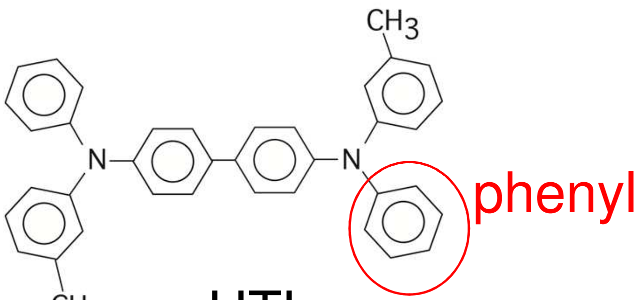
ETL (electron transport), HTL(hole transport),

EML(emitting layer) and other layers (hole blocking…)

consist of small molecules

thermal evaporation in vacuum

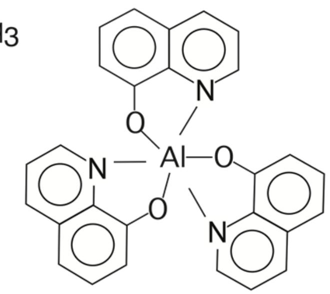
thin layers (20 nm to 200 nm)



HTL

TPD

Alq3



tris (8-hydroxyquinoline) aluminum

ETL

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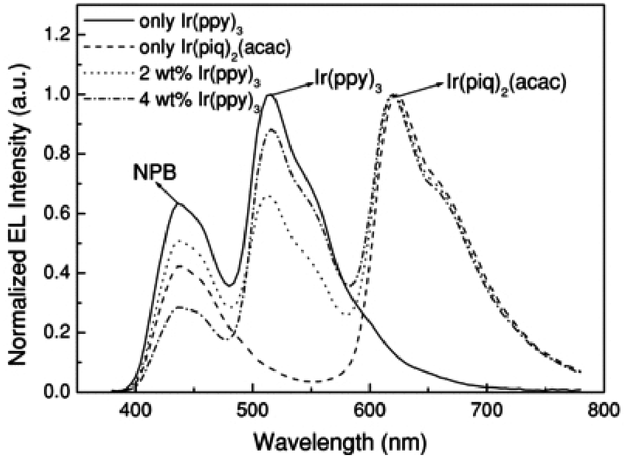
OLED MATERIALS AND DEPOSITION

emitting layer with dopant

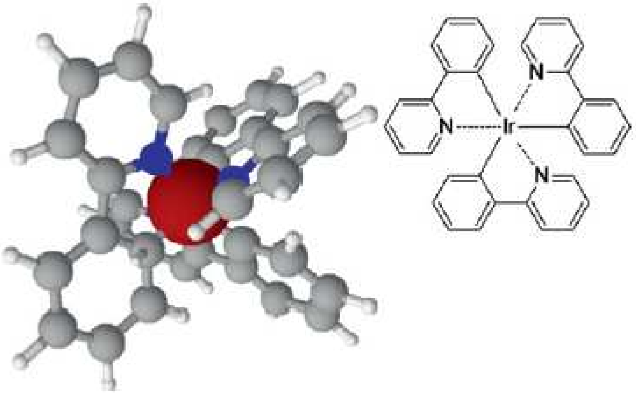
EML transports holes and electrons

dopant determines spectrum

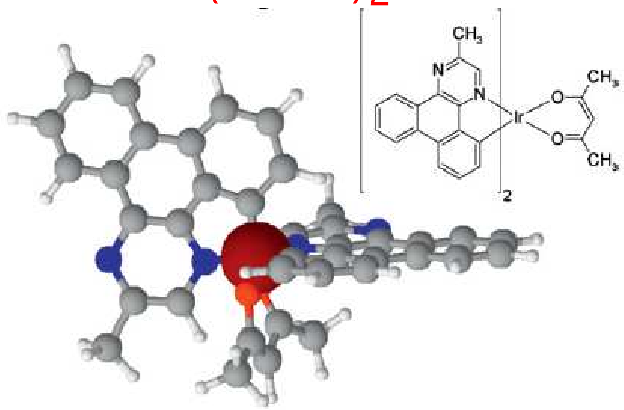
two phosphorescent dopants



Ir(ppy)$_3$



Ir(MDQ)$_2$acac



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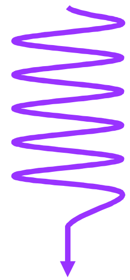
OLED MATERIALS AND DEPOSITION

Polymer OLEDs

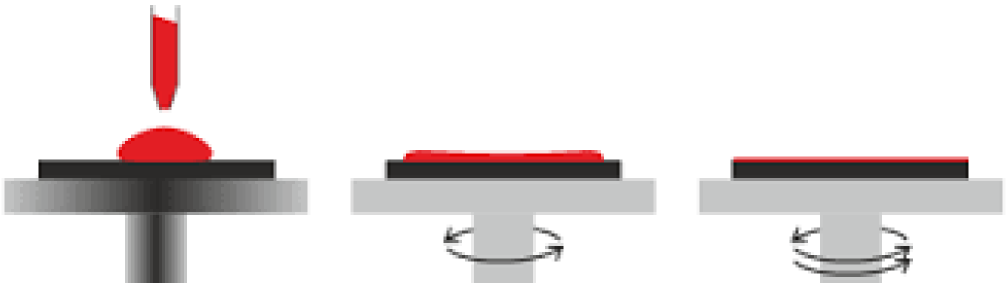
deposition of monomers in solvent by spin coating

polymerization (by UV illumination or heating)

- cheap, large area, problem of contamination
- spin coating can dissolve a previous layer



UV illum.



usually polymer OLEDs are less efficient and have a shorter lifetime

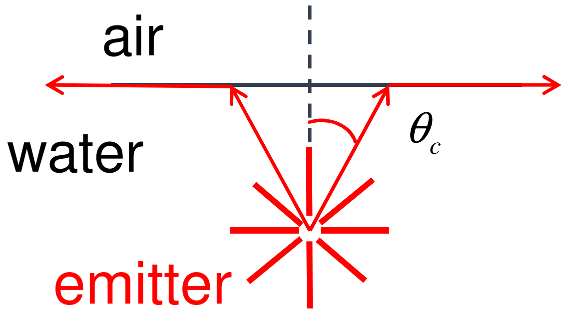
OLED OPTICAL PROPERTIES

Total internal reflection: the emission cone

the critical angle for TIR: $\theta_c = \arcsin\left(\frac{n_{out}}{n_{emitter}}\right)$

the solid angle is:

$$\Omega = \int_{\theta<\theta_c} d\Omega = 2\pi\left(1-\cos\theta_c\right) = 2\pi\left(1-\sqrt{1-\left(\frac{n_{out}}{n_{emitter}}\right)^2}\right)$$

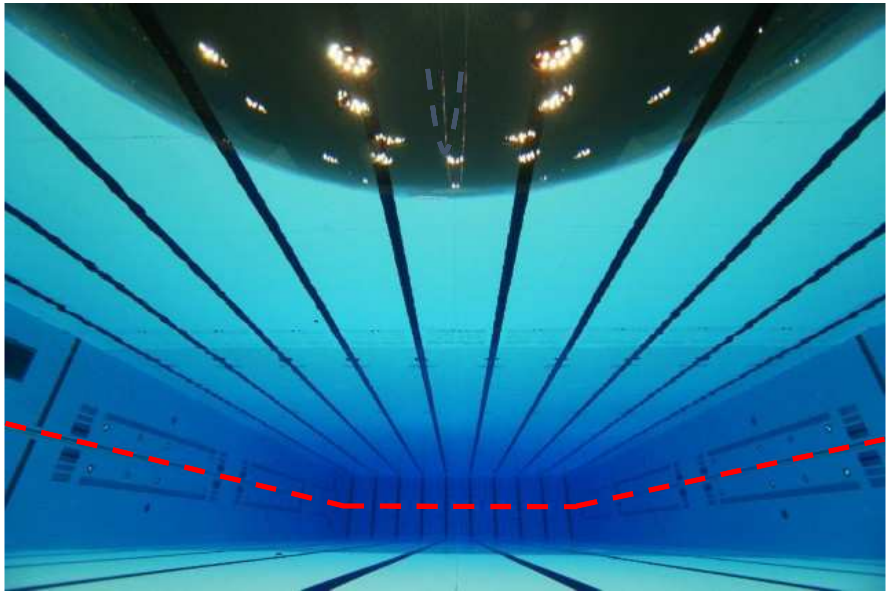


$n_{emitter} = 1.33$

$\theta_c = 49^o$

$\cos\theta_c = 0.66$

$\Omega = 2.14$



TIR in the London Olympics swimming pool

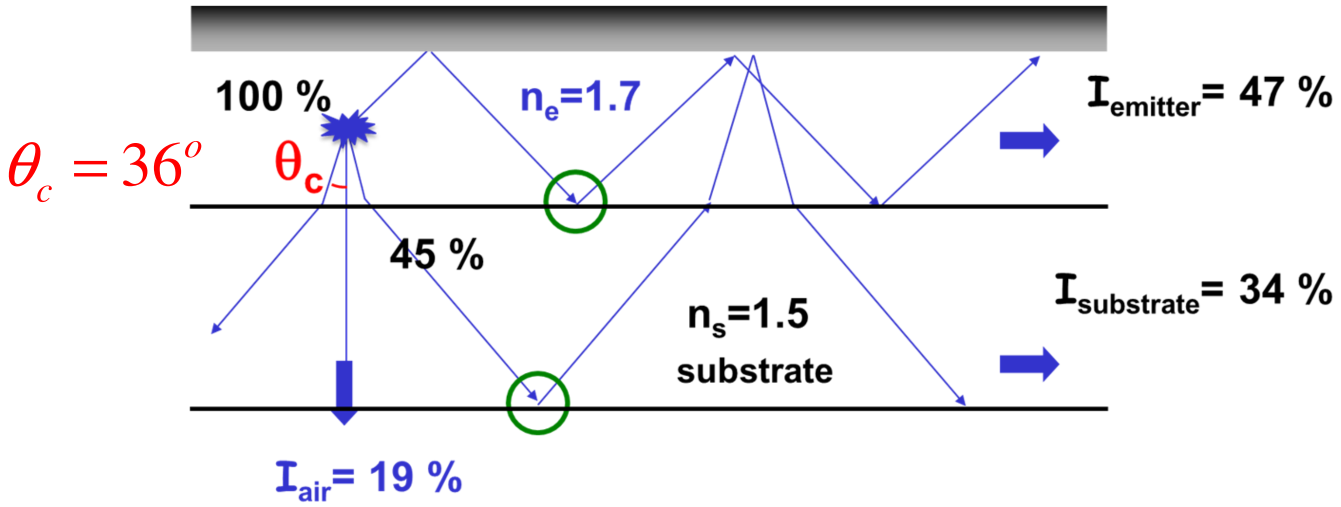
OLED OPTICAL PROPERTIES

Generation of light is isotropic, metallic mirror on top

the critical angle depends on the refractive index: $\theta_c = \arcsin\left(\frac{1}{n_{emitter}}\right)$

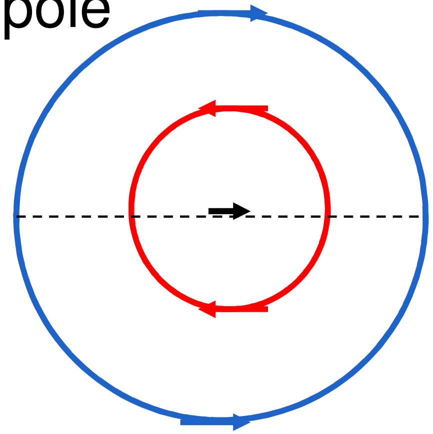
the outcoupling efficiency is given by:

$$\eta_{\text{out}} = \frac{2\Omega}{4\pi} = 1 - \cos\theta_c = 1 - \sqrt{1 - \left(\frac{1}{n_{emitter}}\right)^2}$$



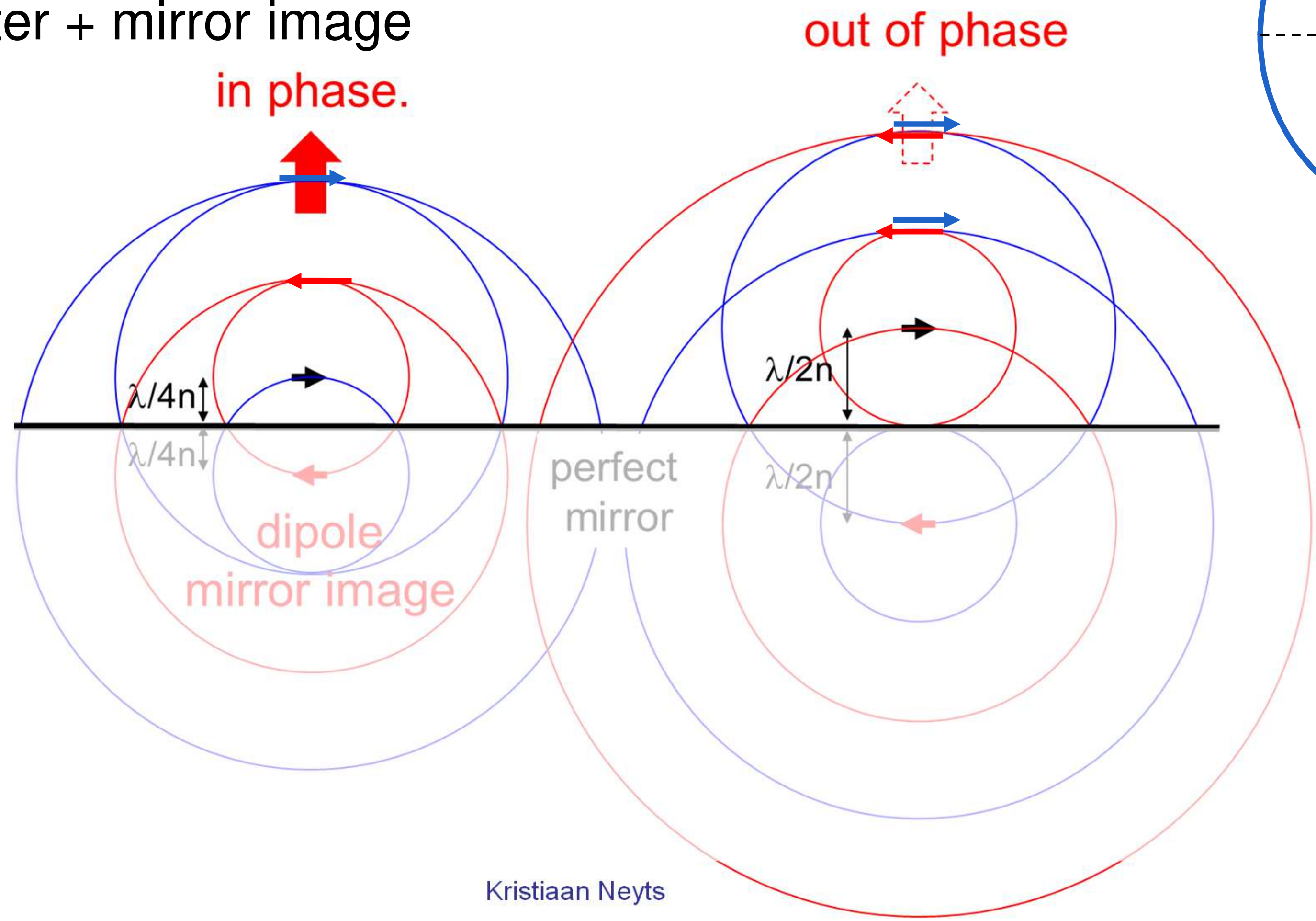
OLED OPTICAL PROPERTIES

single dipole



Interference of emission with reflected light

dipole emitter + mirror image

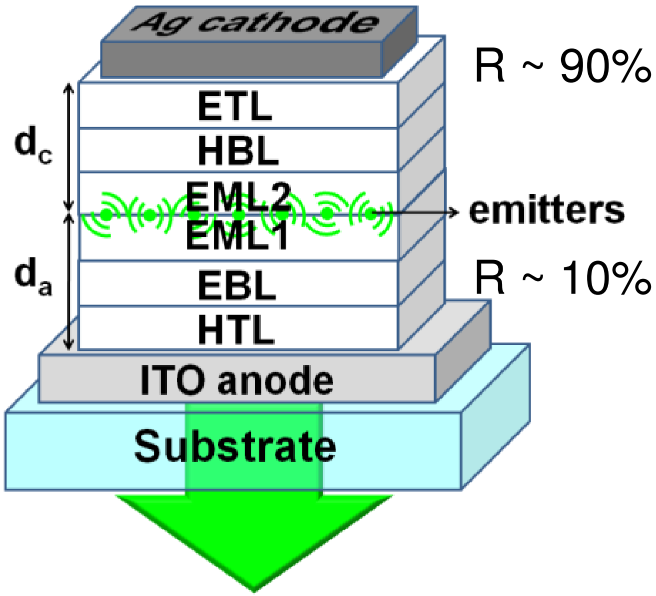


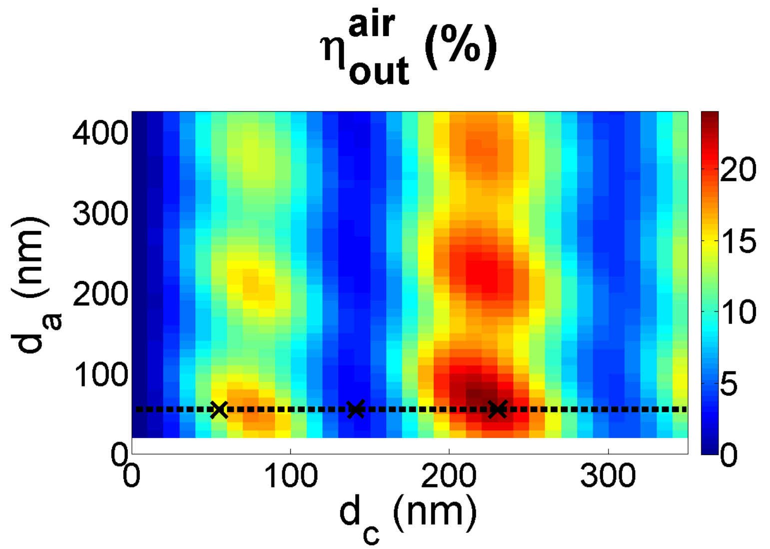
OLED OPTICAL PROPERTIES

Interference of emission with reflected light

reflection at the metallic cathode is most important

distance from the cathode yields interference





OLED OPTICAL PROPERTIES

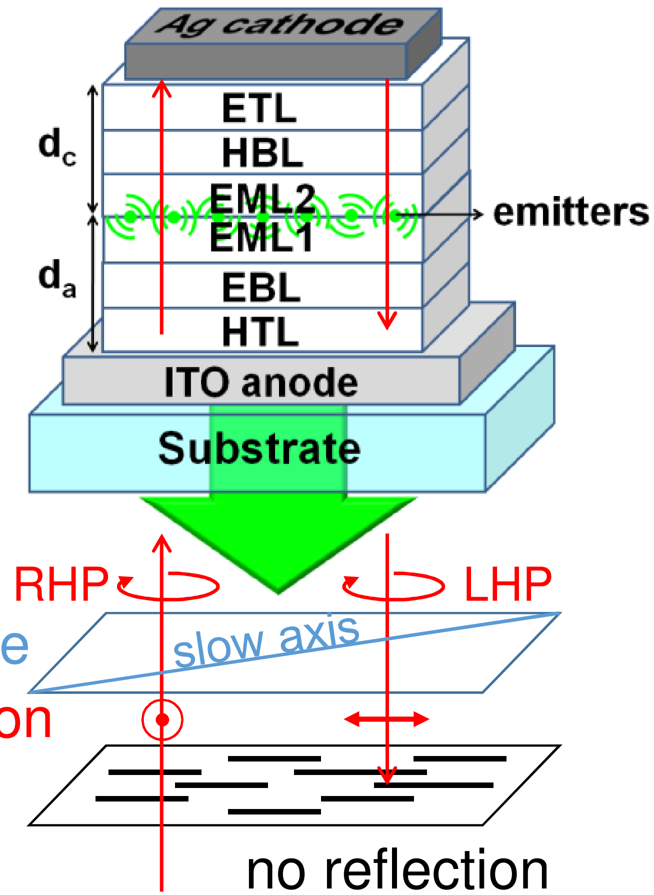
avoid reflection of ambient light

use a quarter wave plate

with a polarizer

half of the emission

is blocked too...



quarter wave plate

polarization

polarizer
(absorbing direction is shown)

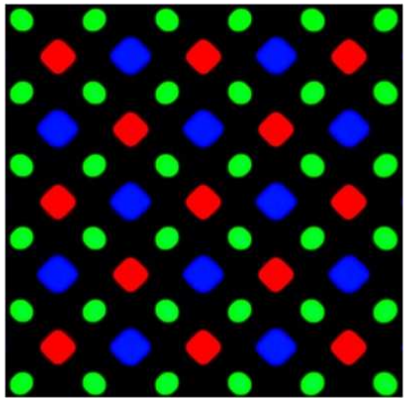
no reflection

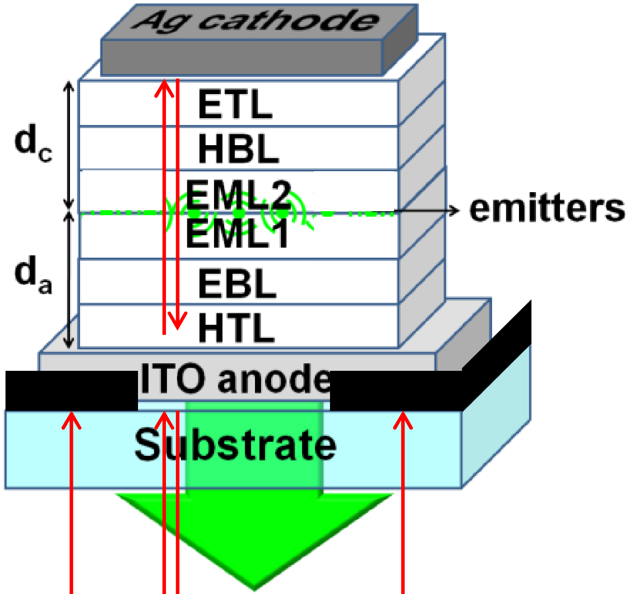
incident ambient light

OLED OPTICAL PROPERTIES

avoid reflection of ambient light
by using a black grid
and color filters

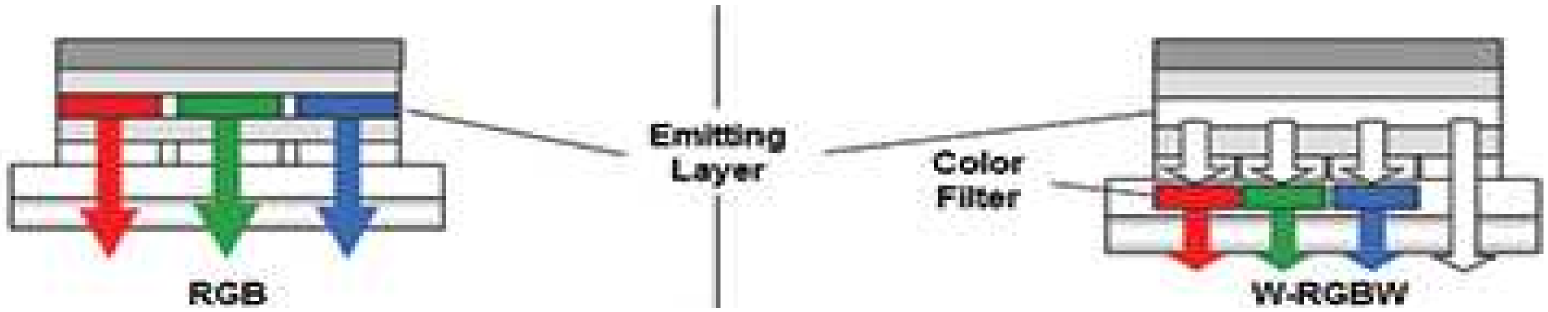
most of the ambient light
is absorbed





OLED COLOR BY WHITE

instead of RGB pixels: white pixel with color filters



high efficiency

patterning of 3 OLEDs
deposition is a challenge

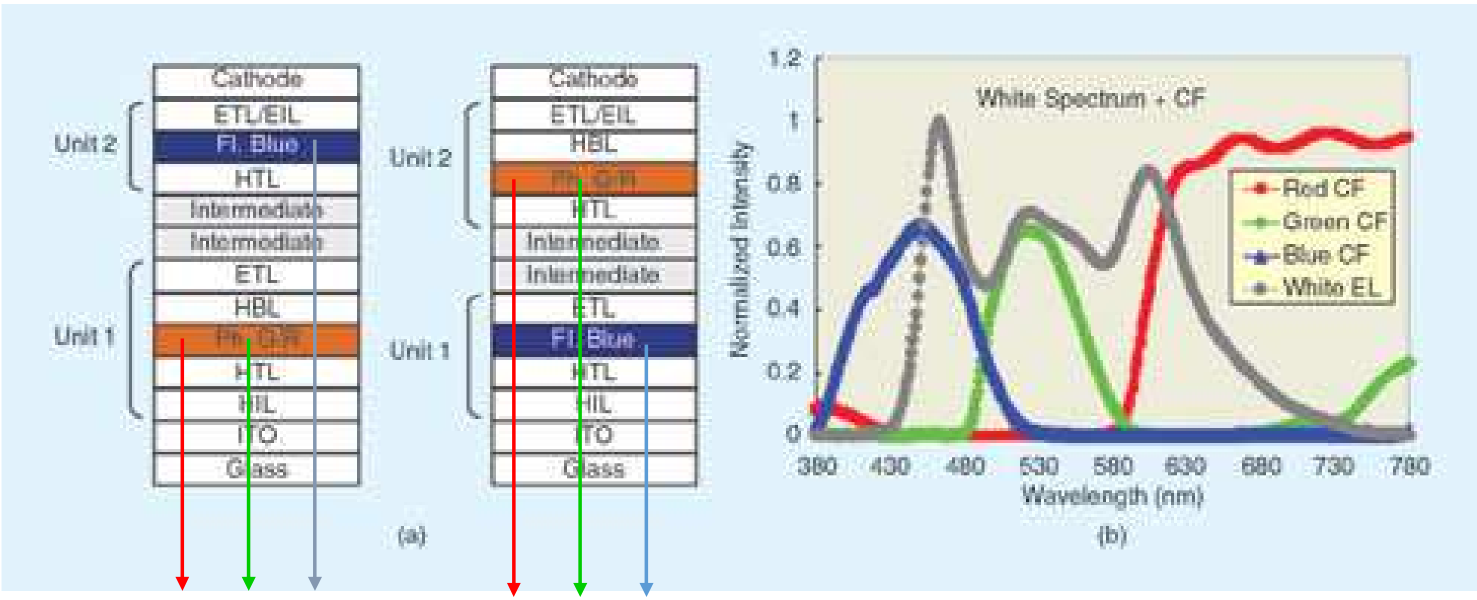
one white stack
patterned color filters
easy production

less efficient

OLED COLOR BY WHITE

white pixel with color filters

tandem OLED: blue emitting OLED + yellow emitting OLED
in series with each other: same current, double voltage



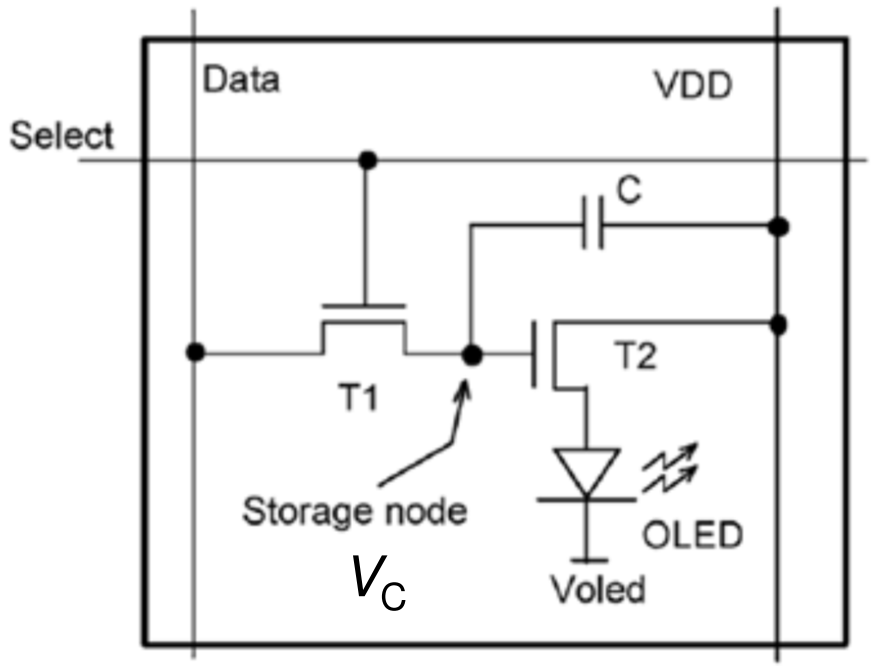
AMOLED – ACTIVE MATRIX OLED

driving the OLED pixels with **transistors**
OLEDs are driven by current

row selection pulse
T_1 is conducting
charge is transferred to C

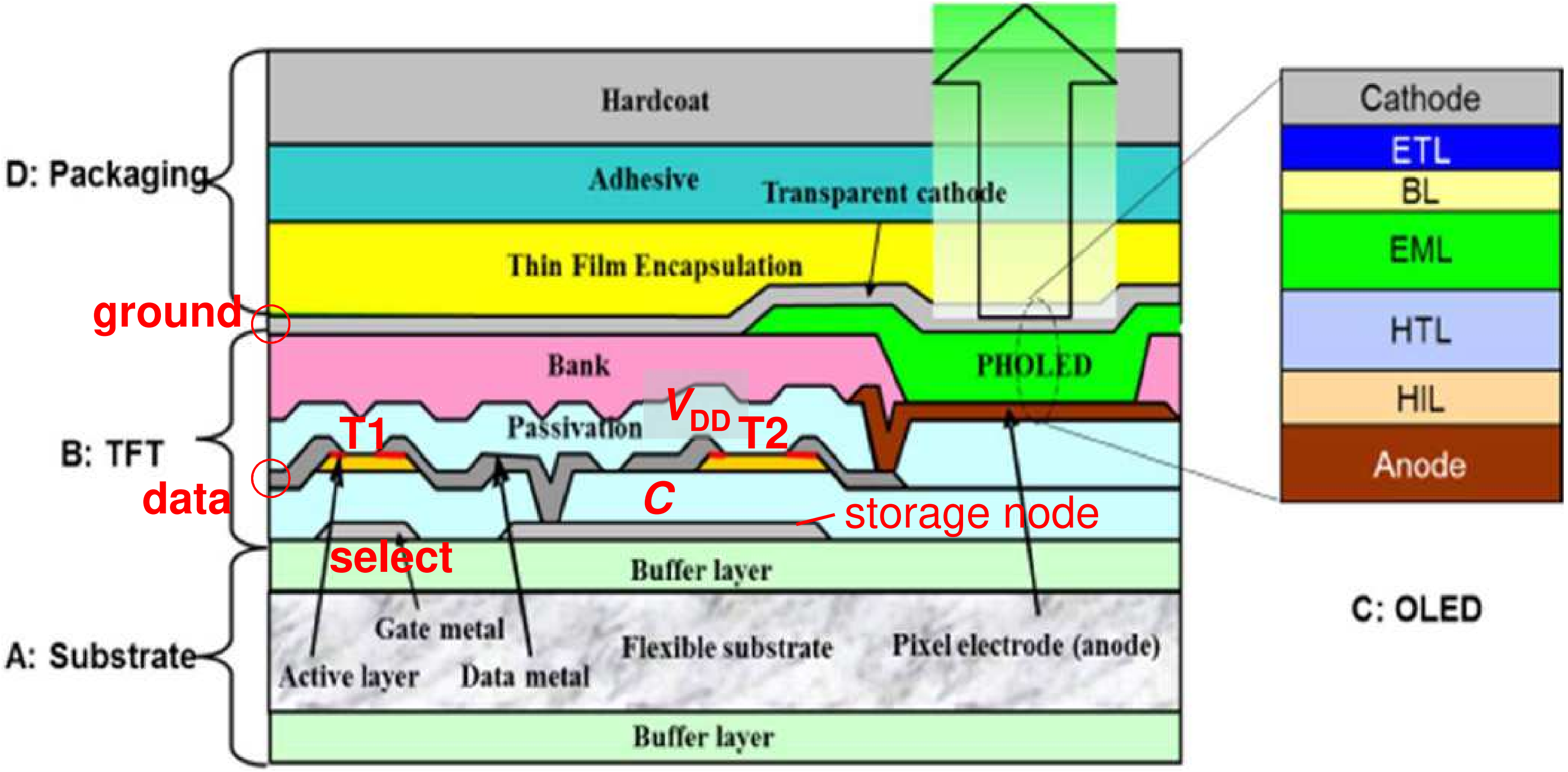
OLED (and T_2) current
depend on gate voltage V_C

dissipation $V_{DD}.I_{OLED}$
not only in the OLED
but also in T_2



AMOLED – ACTIVE MATRIX OLED

driving the OLED pixels with transistors (here: top emitting)



H. Pang et al. SPIE newsroom 2012

OLED STRENGTHS AND WEAKNESSES

strenghts

- good color purity RGB
- excellent dark state when there is no current
- very thin devices, flexible possible
- can be efficient (with RGB pixels)

weaknesses

- difficult to obtain high brightness (blue in particular)
- encapsulation problems, lifetime (blue in particular)
- homogeneity and stability (in OLEDs and also in transistors)

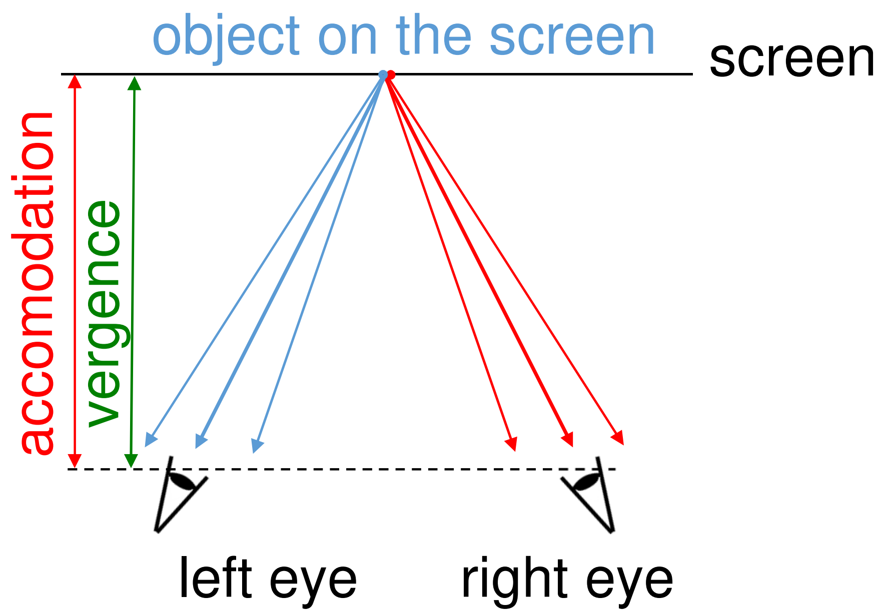
3D DISPLAYS

projection stereoscopy with glasses (3D cinema)

images for left and right eye on the same screen

accomodation distance = distance to the screen

vergence distance: larger or smaller than distance to screen



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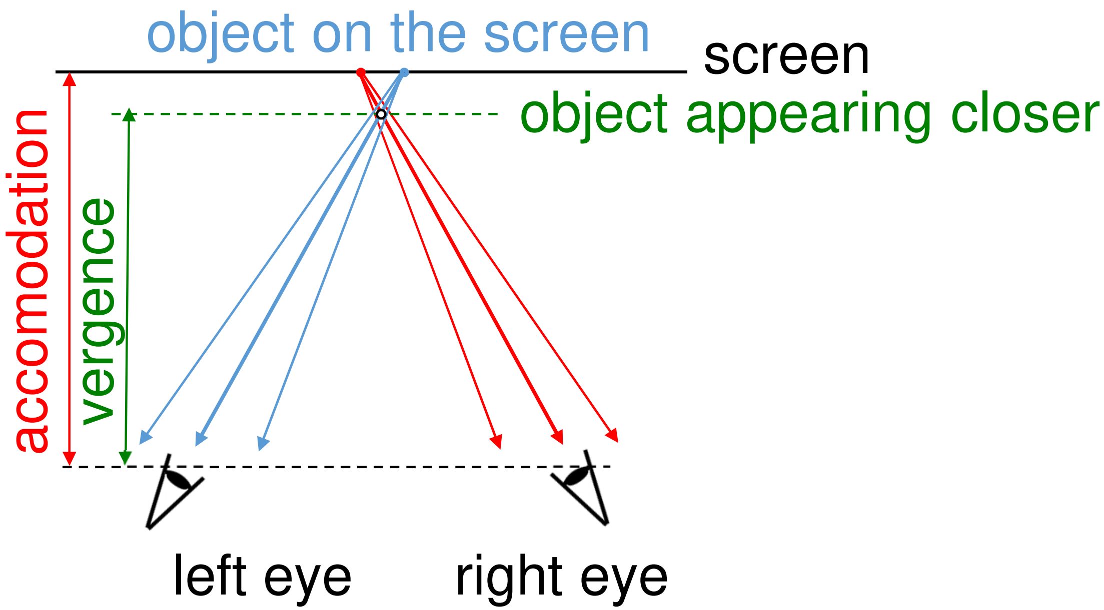
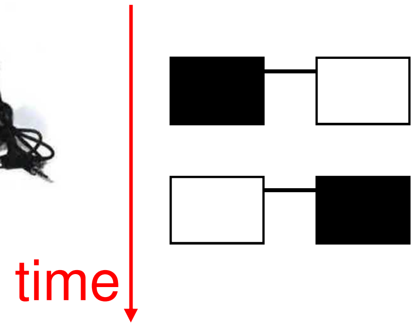


3D DISPLAYS

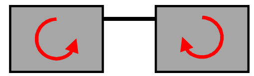
projection stereoscopy with glasses (3D cinema)

separation of images:

- by time (speed / 2)
  - active glasses (battery)
  - switch on and off alternately
  - expensive glasses



- by polarization (LHCP and RHCP)
  - screen must maintain polarization
  - expensive screen
  - (linear polarization is not OK...)



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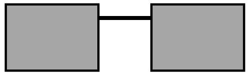
3D DISPLAYS

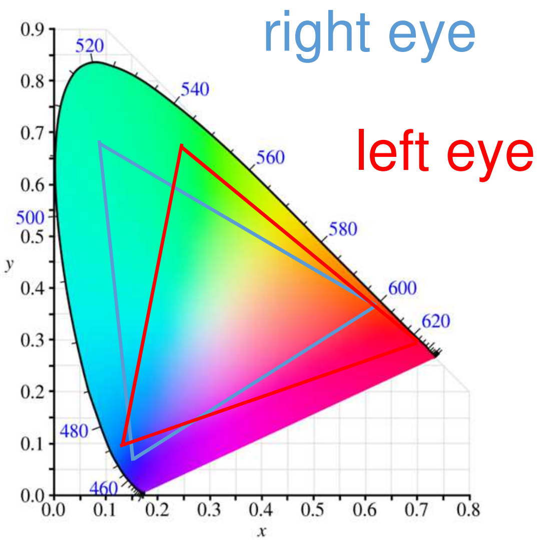
projection stereoscopy with glasses (3D cinema)

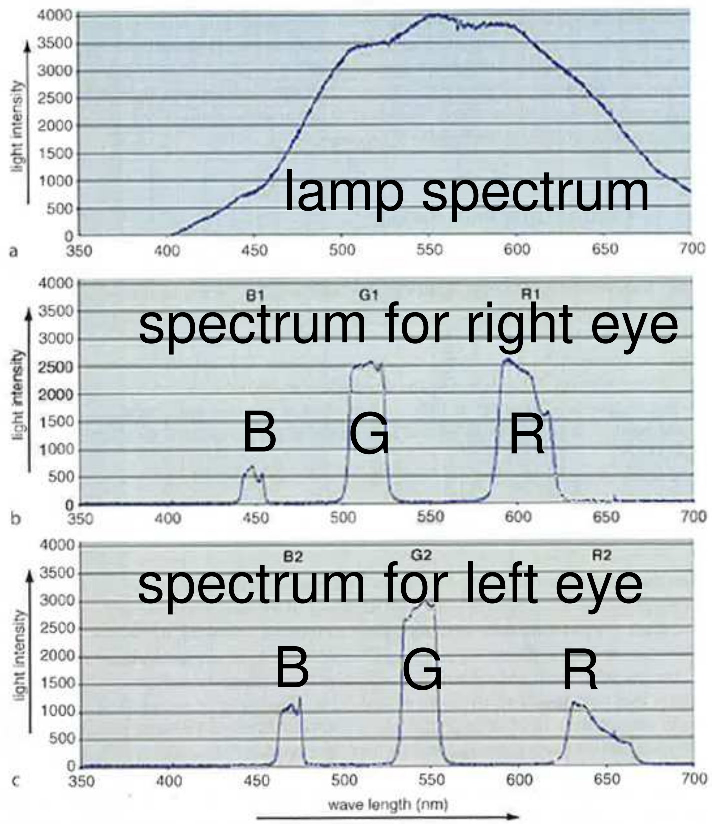
separation of images:

- by wavelength interval



two shifted spectral filters



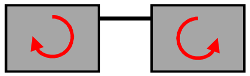


3D DISPLAYS

stereoscopy display with glasses (3D TV)

separation of images by polarization

- RHCP and LHCP

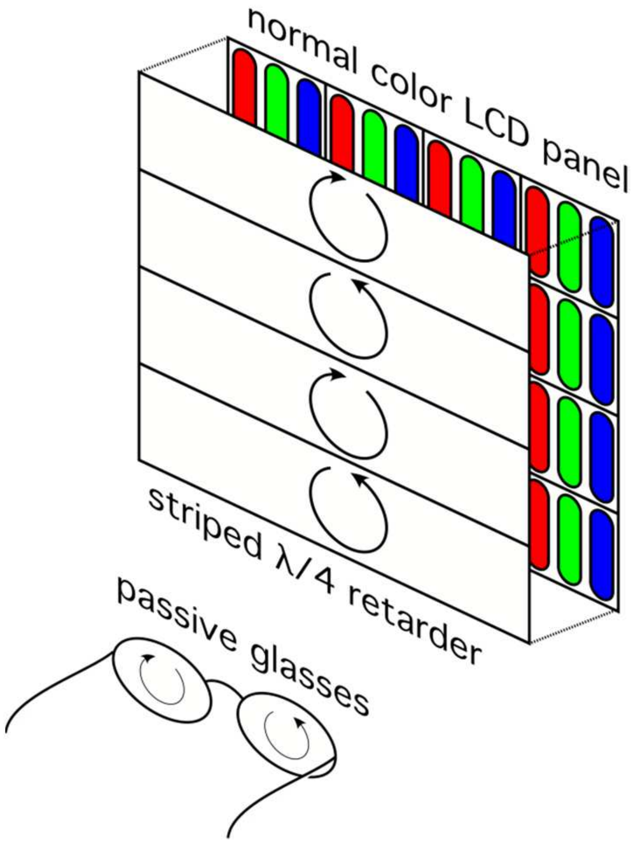


realized by LCD TV

resolution loss: ½

without glasses:

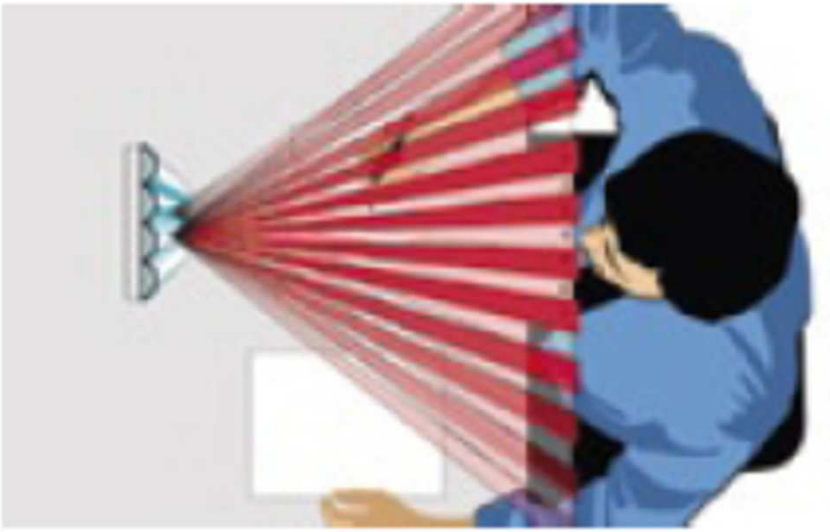
normal TV at full resolution



3D DISPLAYS

Multi-view displays

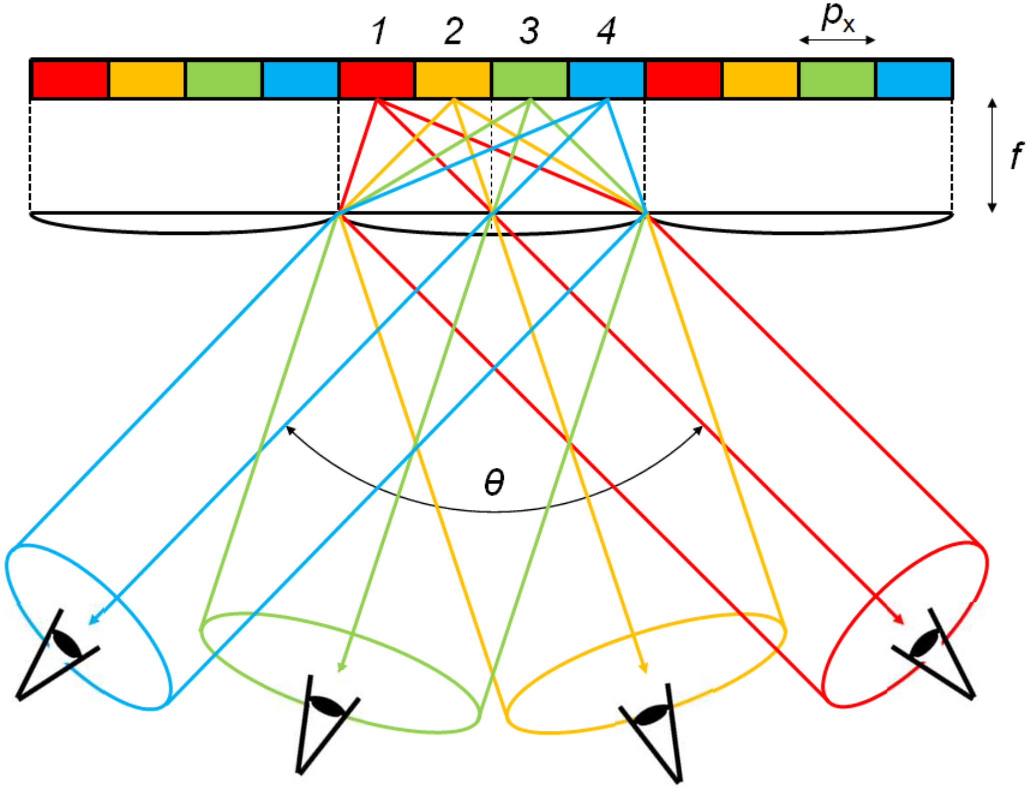
- different images are emitted in different directions.
- for example: 12 views, from left to right
- the left and right eye should see only one image



3D DISPLAYS

Multi-view displays

- lenticular lenses to show 4 different images in 4 different directions



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3D DISPLAYS

Near-to-eye 3D

Viewmaster

Google Cardboard

Oculus Rift

Liquid Crystals and Photonics

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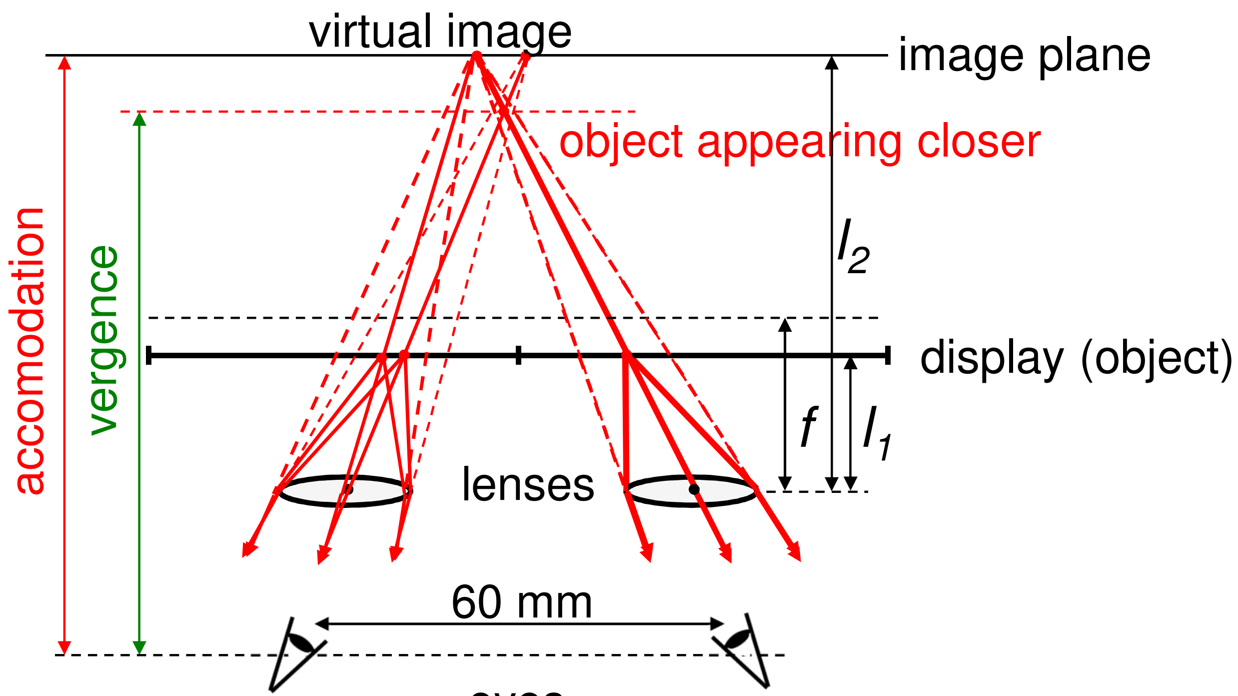
3D DISPLAYS

Near-to-eye 3D

Two images on two separate displays

Lens projects the image to a larger distance

$$\frac{1}{f} = \frac{1}{l_1} - \frac{1}{l_2}$$



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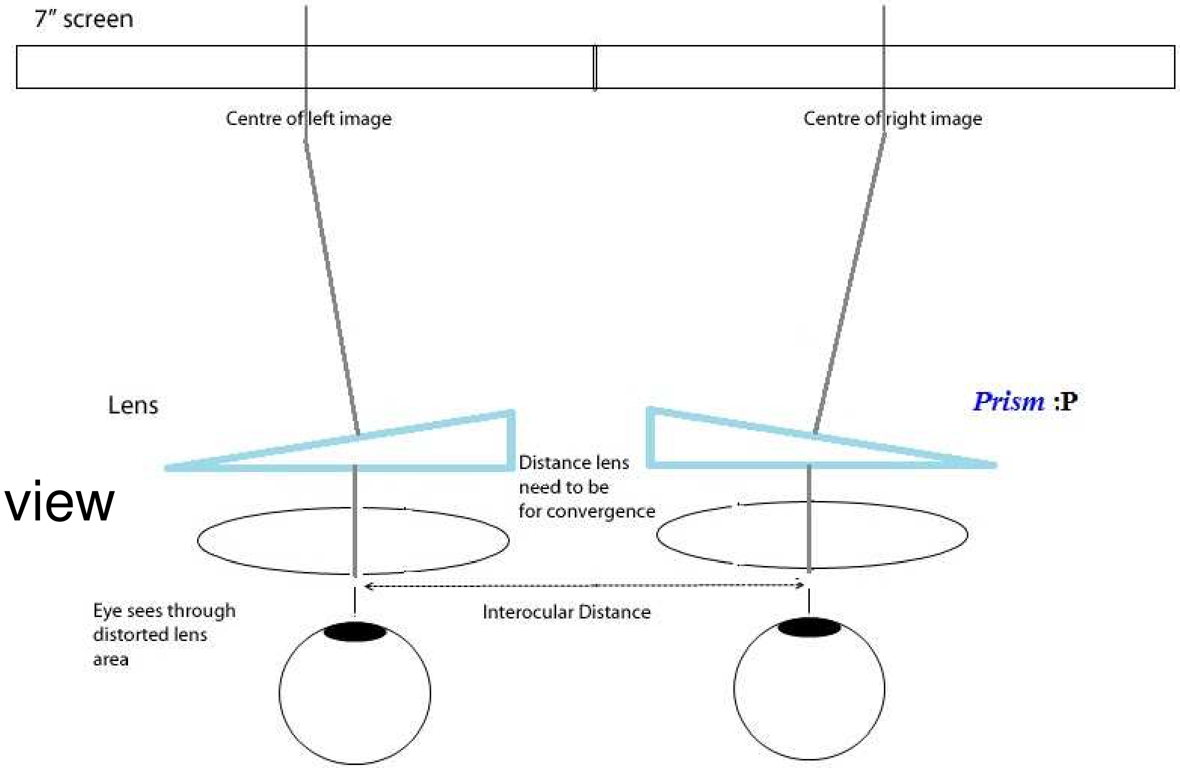
3D DISPLAYS

Near-to-eye 3D

Oculus Rift

larger field of view



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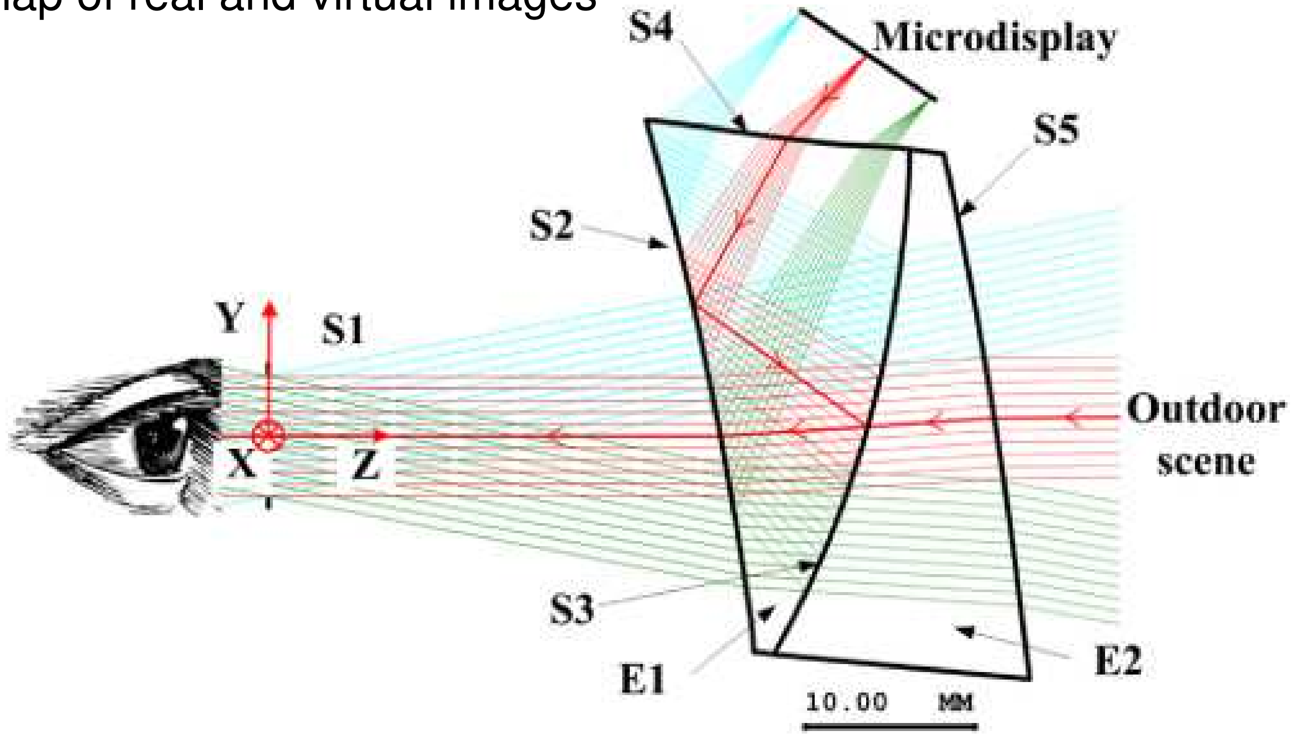
3D DISPLAYS

Augmented reality

semi-transparent near-to-eye display (similar to Google glass)

reflector with focal distance, virtual image at infinity

overlap of real and virtual images



3D DISPLAYS

Augmented reality

see-through near-to-eye display (similar to Google glass)

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