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

Spatial light modulator

OLEDs

Liquid Crystals and Photonics

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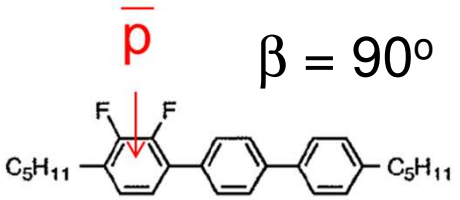
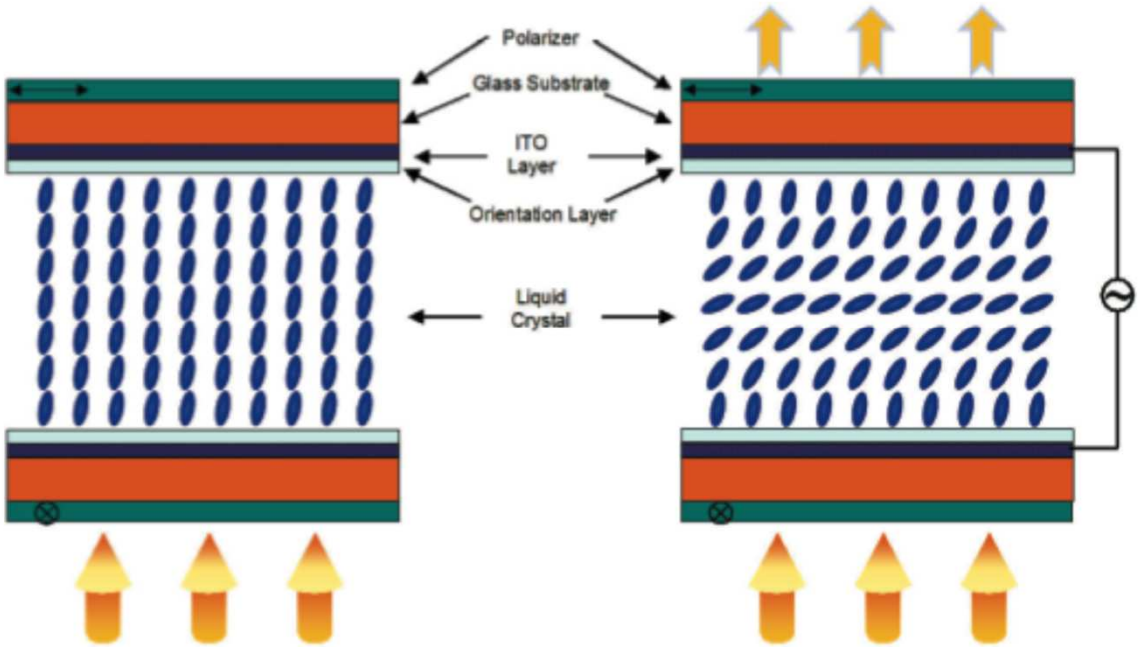
VERTICALLY ALIGNED NEMATIC (VAN)

Initially vertically aligned, and $\Delta\varepsilon < 0$
with particular alignment material





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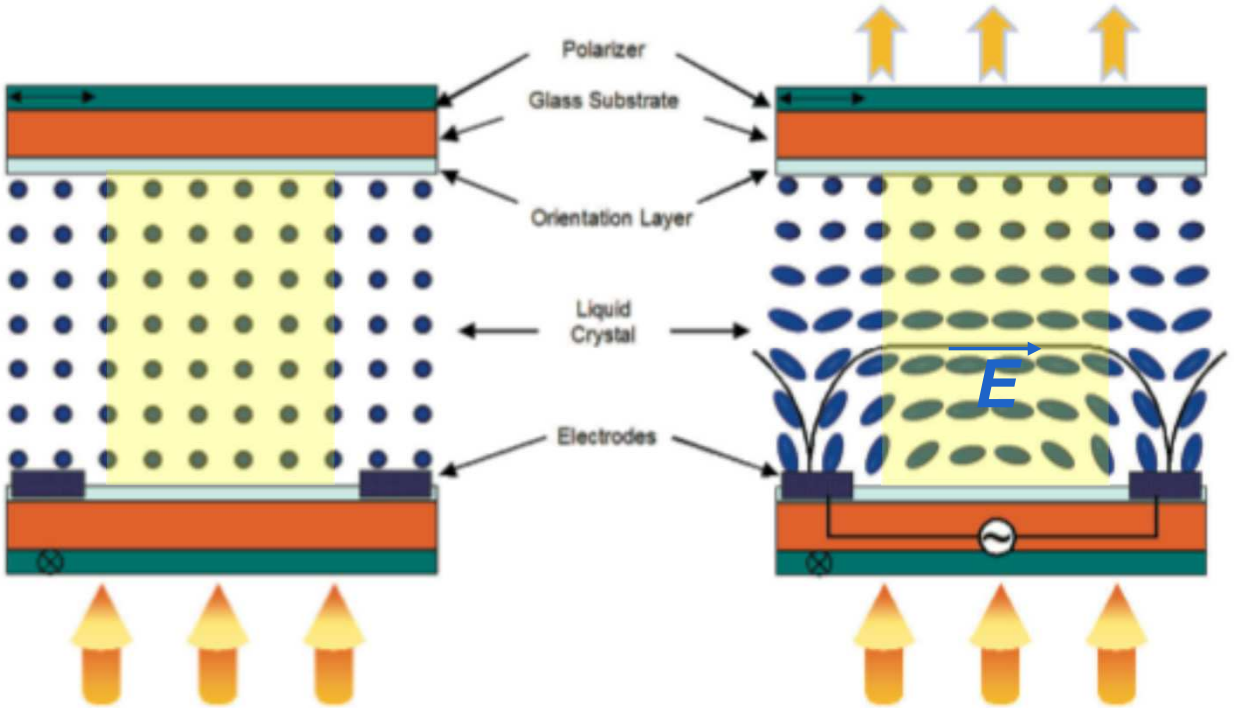
IN PLANE SWITCHING (IPS) MODE

initially: director homogeneous

with voltage: director reorients in plane



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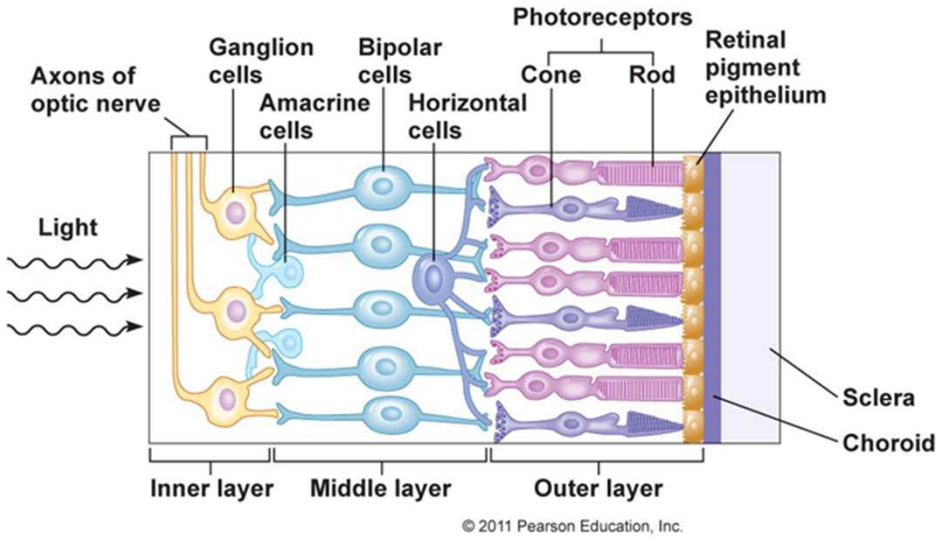
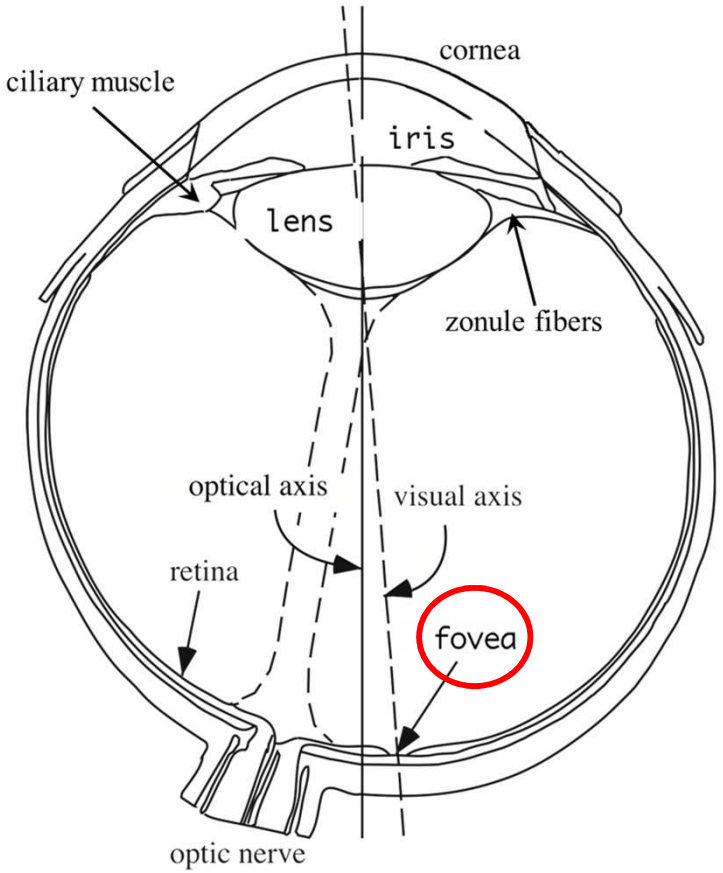
THE HUMAN VISUAL SYSTEM

- eye lens
- photosensitive receptors in fovea
  - fovea with cones (where you look at)
  - wide area: rods
- axons: transfer the information
- blind spot



Right eye

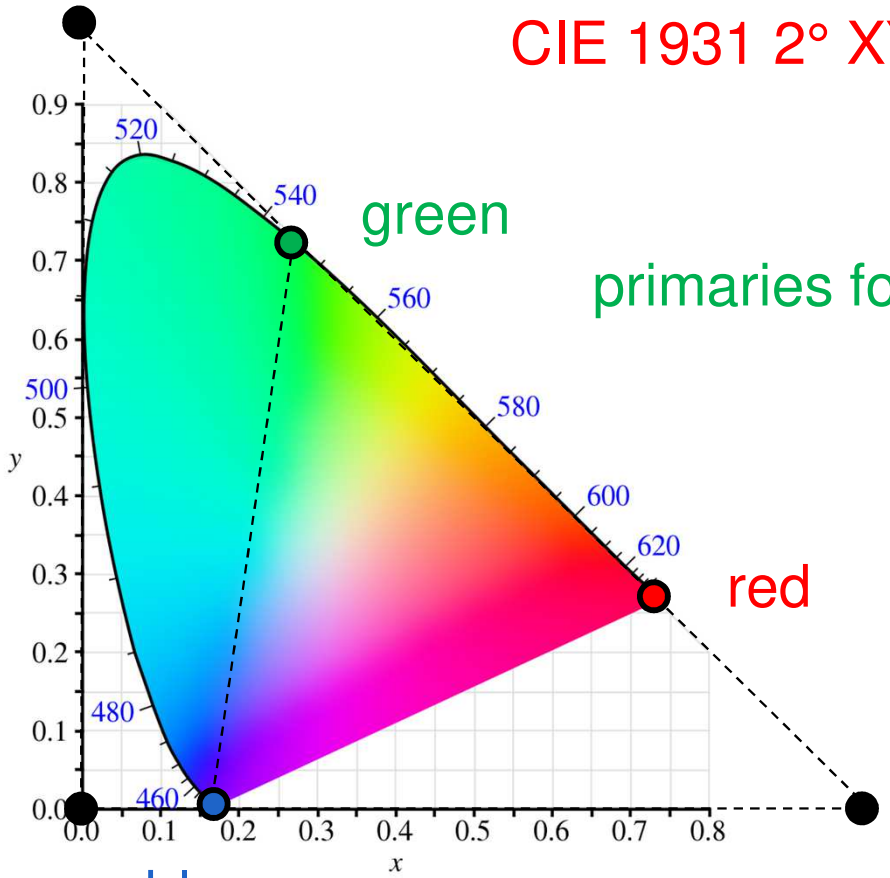


130 million photoreceptors
1 million nerve fibres

THE HUMAN VISUAL SYSTEM

primaries for XYZ

$$y = \frac{Y}{X + Y + Z}$$



CIE 1931 2° XYZ color system

green

primaries for RGB

red

blue

$$x = \frac{X}{X + Y + Z}$$

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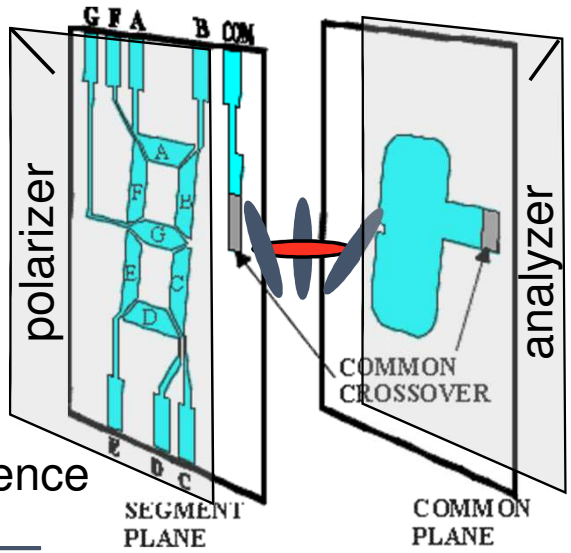
DIRECT DRIVING

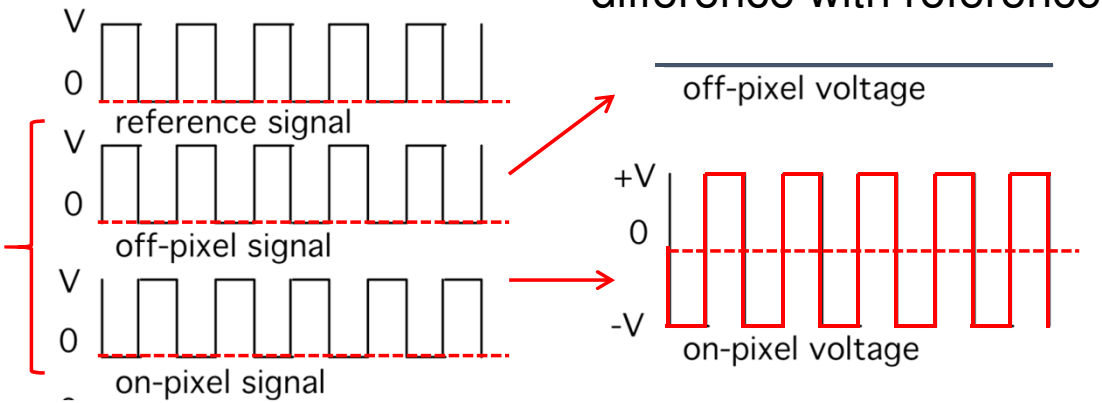
LCD reacts to $|V^2|$

AC driving to avoid chemical reactions in the LC

one electrode per segment

reflective display





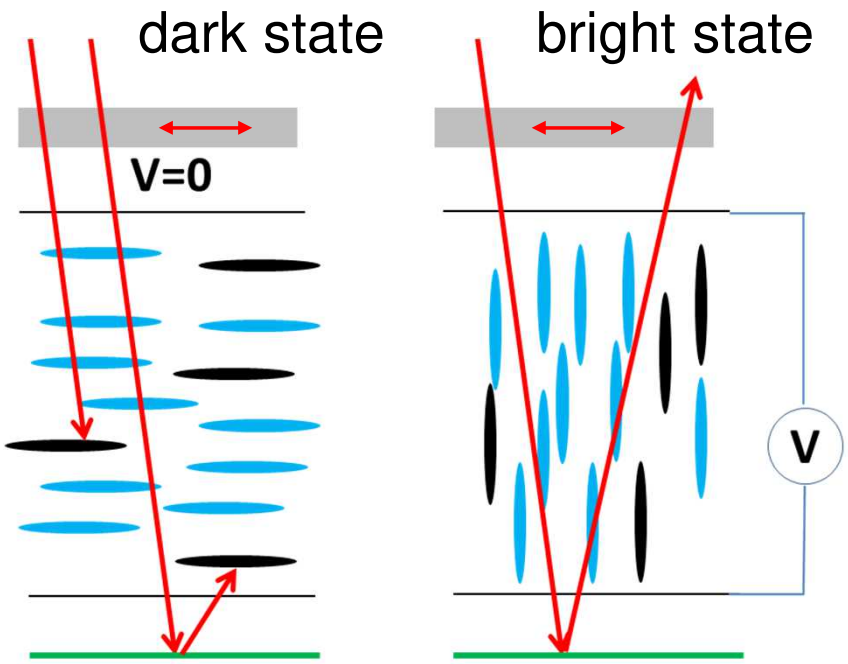
TN – LCD

off: bright state

on: dark state

GUEST HOST LCD

dye molecules have anisotropic absorption
dye molecules reorient with the LC



Liquid Crystals and Photonics

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ACTIVE MATRIX DRIVING (AM-LCD)

TRANSISTORS

- amorphous Silicium (a-Si:H), 'bottom-gate
- At zero gate voltage

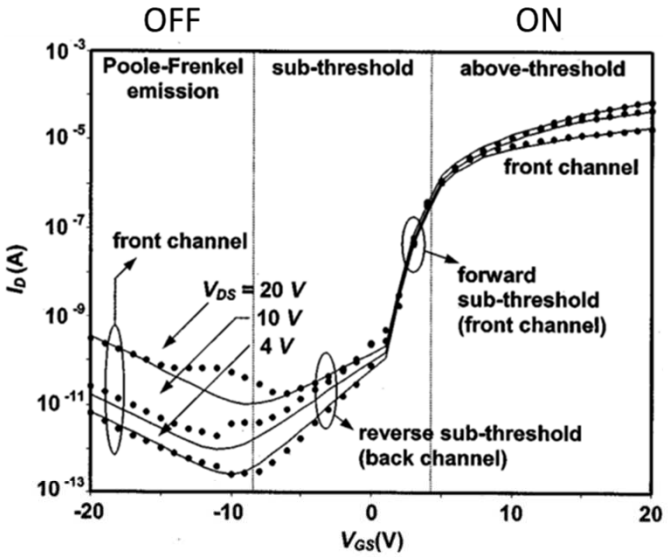
→ high resistance

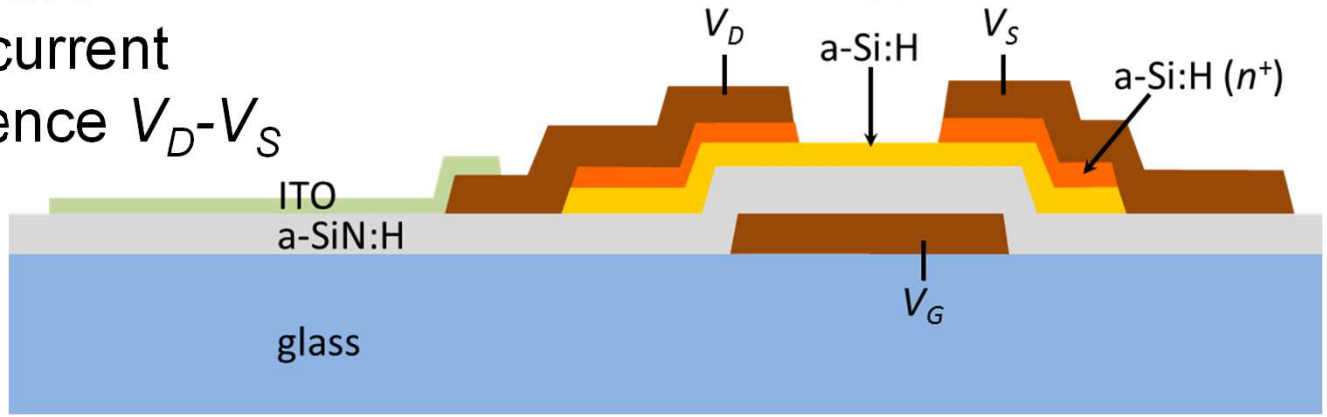
→ no current = OFF-state

- At positive gate voltage

→ channel conductive

→ a source-drain current if voltage difference V_D-V_S



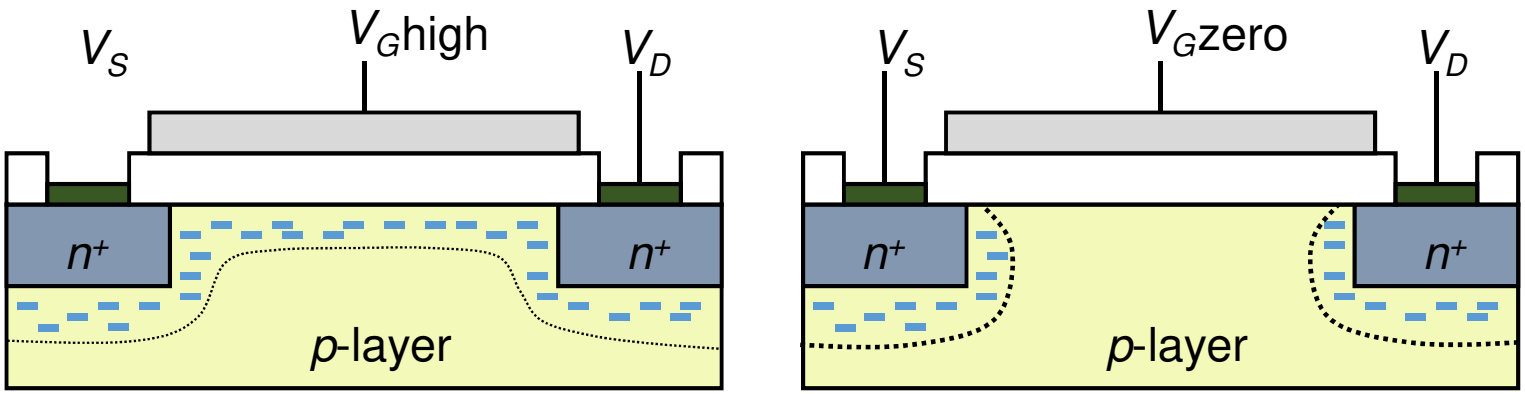


ACTIVE MATRIX DRIVING (AM-LCD)

Display data processing:

TFT technology

- Similar to MOSFET (metal-oxide-semiconductor field-effect-transistor)



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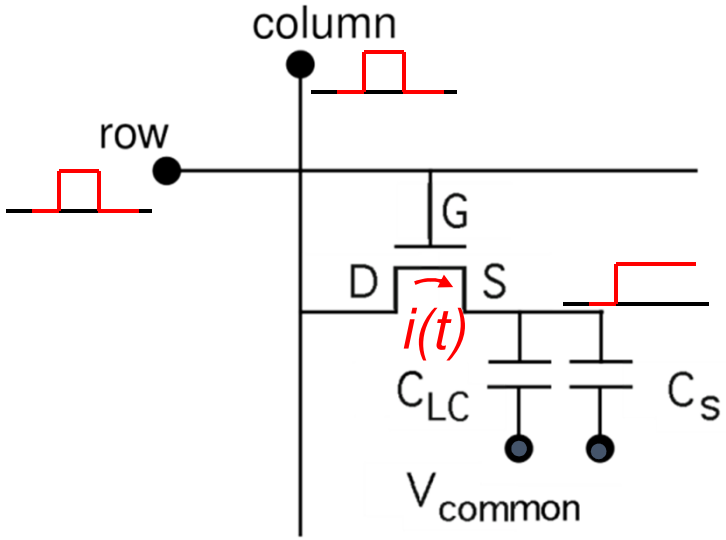
ACTIVE MATRIX DRIVING (AM-LCD)

Matrix of pixels (full HD: 1920 x 1080 square pixels)

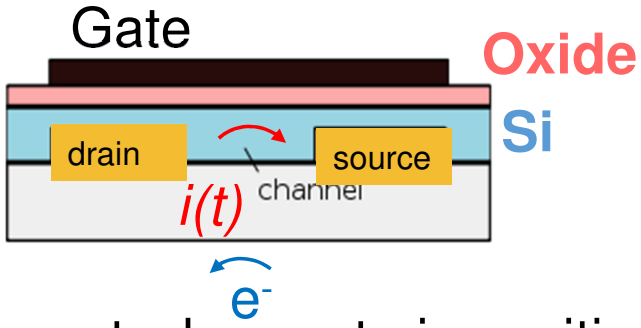
Total number of electrodes:

1920 column electrodes, 1080 row electrodes, 1 common el.

LC: C_{LC}; capacitor: C_S; transistor for every pixel (2 073 600)



Si or IGZO thin film transistor
Field Effect Transistor (FET)
n-channel (electrons)

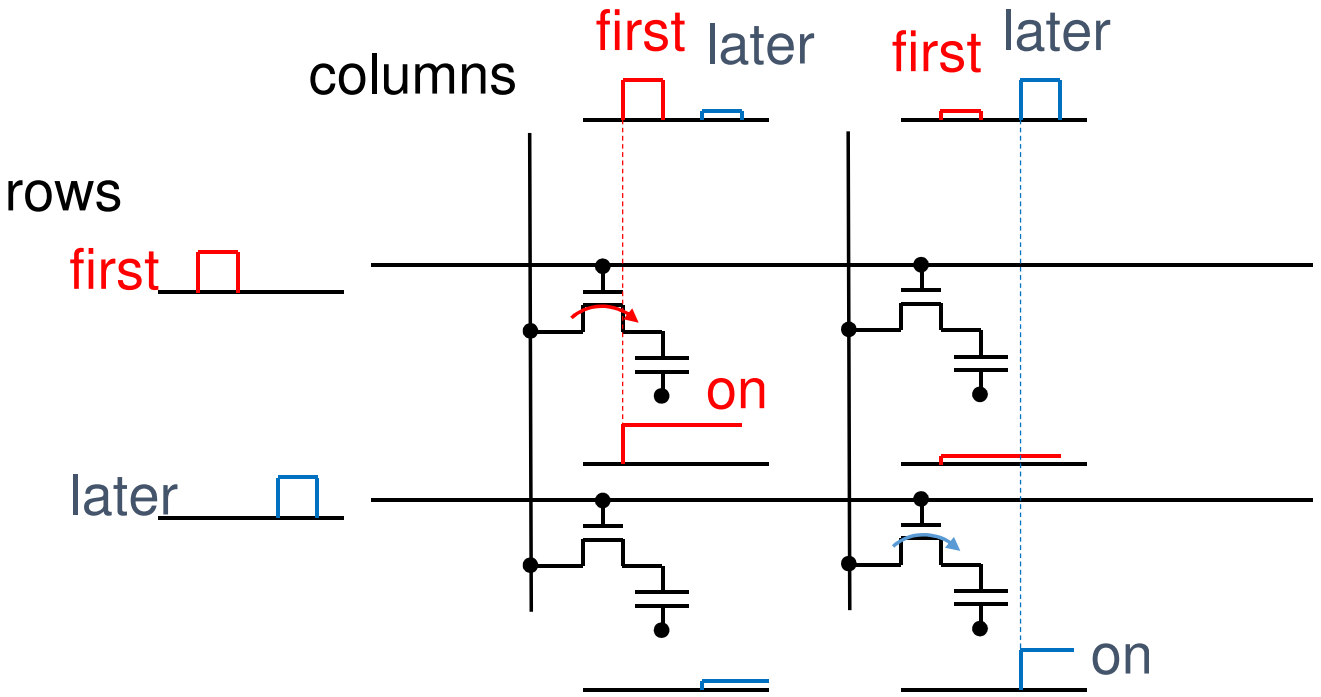


only current when gate is positive

ACTIVE MATRIX DRIVING (AM-LCD)

Matrix driving of rows and columns

- rows driven one after the other (row time = frame time / *N*)
- column voltages determine the grey scale



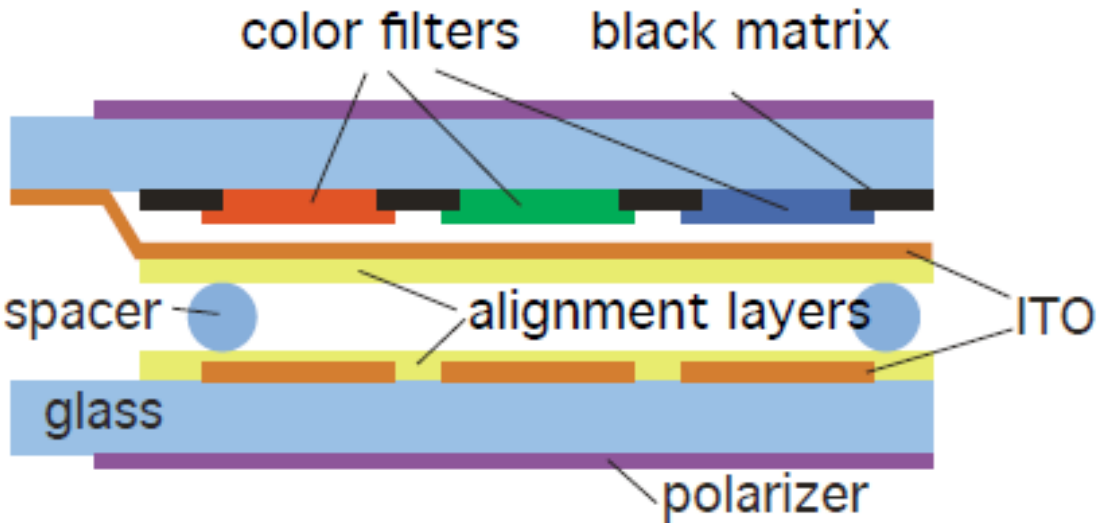
LCD CROSS SECTION

arrangement :

color filters, black matrix (top substrate)

TFT and pixel electrodes (bottom substrate)

polarizers, alignment, ITO, LCD



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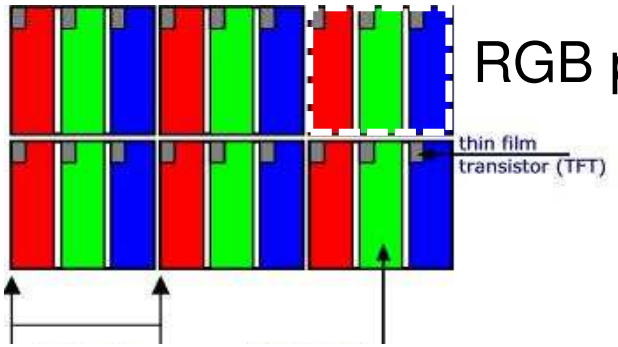
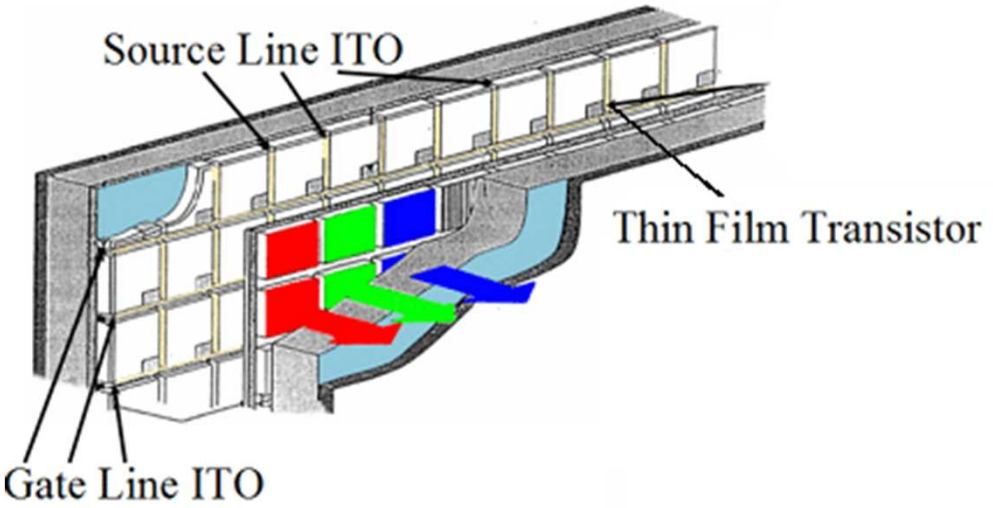
ACTIVE MATRIX DRIVING (AM-LCD)

Matrix driving of rows and columns, three colors per pixel

- rows driven one by one (row time = frame time / *N*)
- column voltages determine the grey scale





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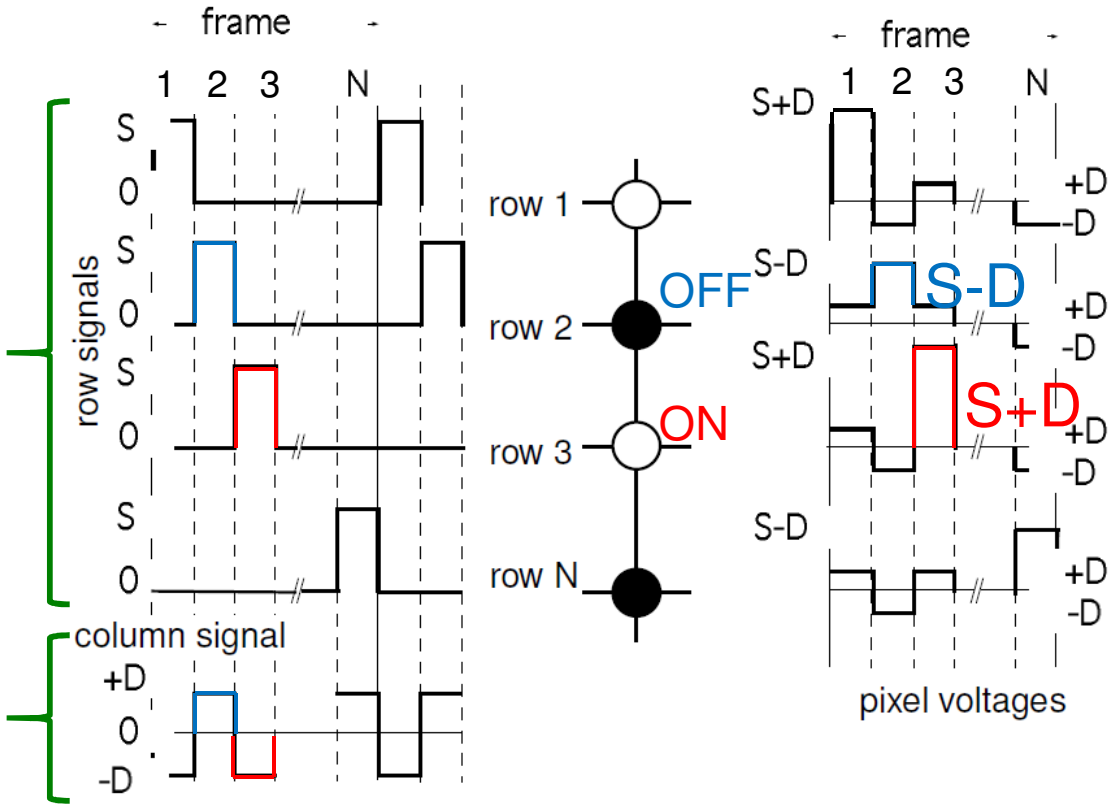
PASSIVE MATRIX DRIVING (WITHOUT TRANSISTORS)

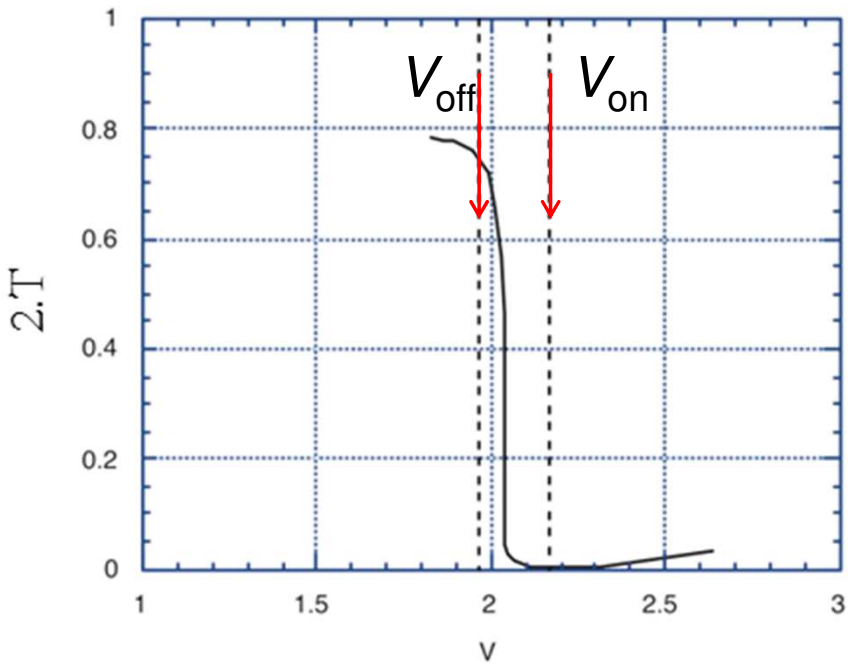
- row selection pulse +S or 0
- column signal between +D and -D

total signal:
S+D, S-D, +D,-D



PASSIVE MATRIX DRIVING (WITHOUT TRANSISTORS)

maximize V_{on}/V_{off}

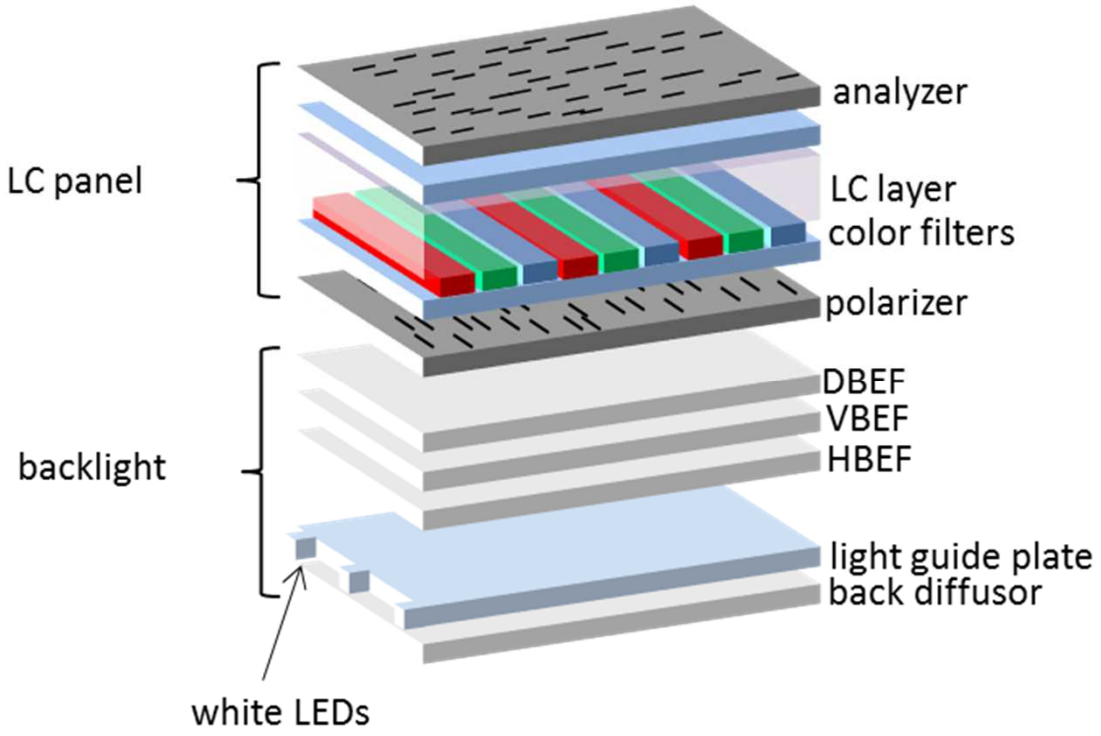


For N=100 we find S/D = 10 and V_{on}/V_{off} =1.106

STN is required to obtain sufficient contrast on/off

BACKLIGHT AND OPTICS

Structure of LCD with backlight



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BACKLIGHT AND OPTICS

light sources: CCFL or LED: back area or side area

emits RGB light

cold cathode fluorescent light

light emitting diodes

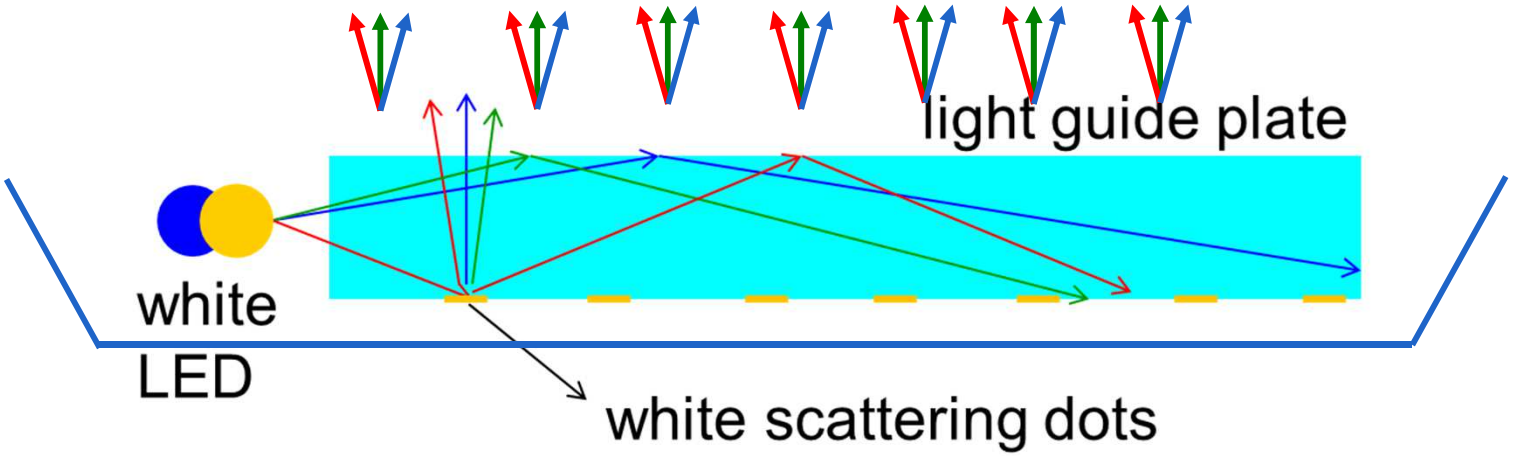
blue with yellow phosphor

BACKLIGHT AND OPTICS

side illumination by using a light guide plate

light guide by total internal reflection

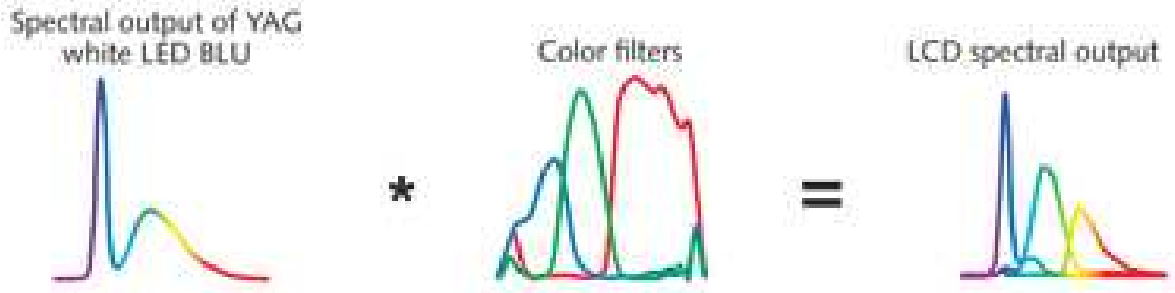
emission by small scattering areas



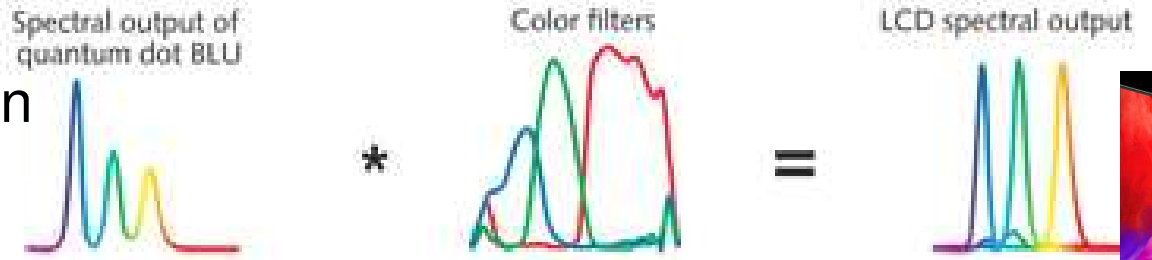
BACKLIGHT AND OPTICS

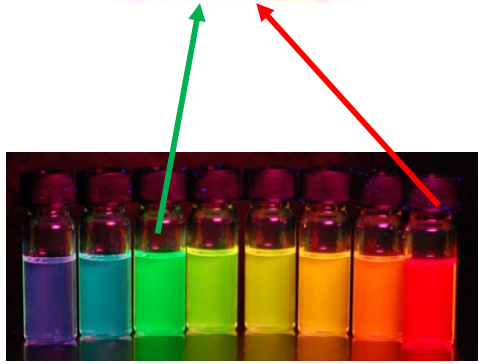
saturated RGB colors in the backlight?

yellow phosphor



red/green Qdots





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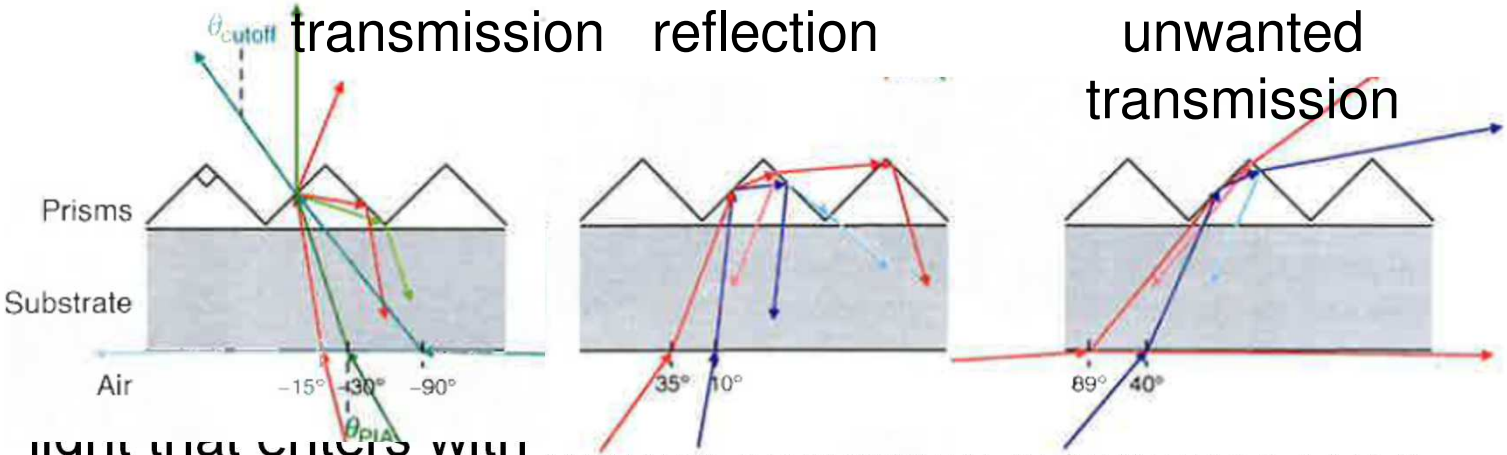
BACKLIGHT AND OPTICS

brightness enhancement film: 45 degree prisms
more light near perpendicular
less light at high angles (non-Lambertian)



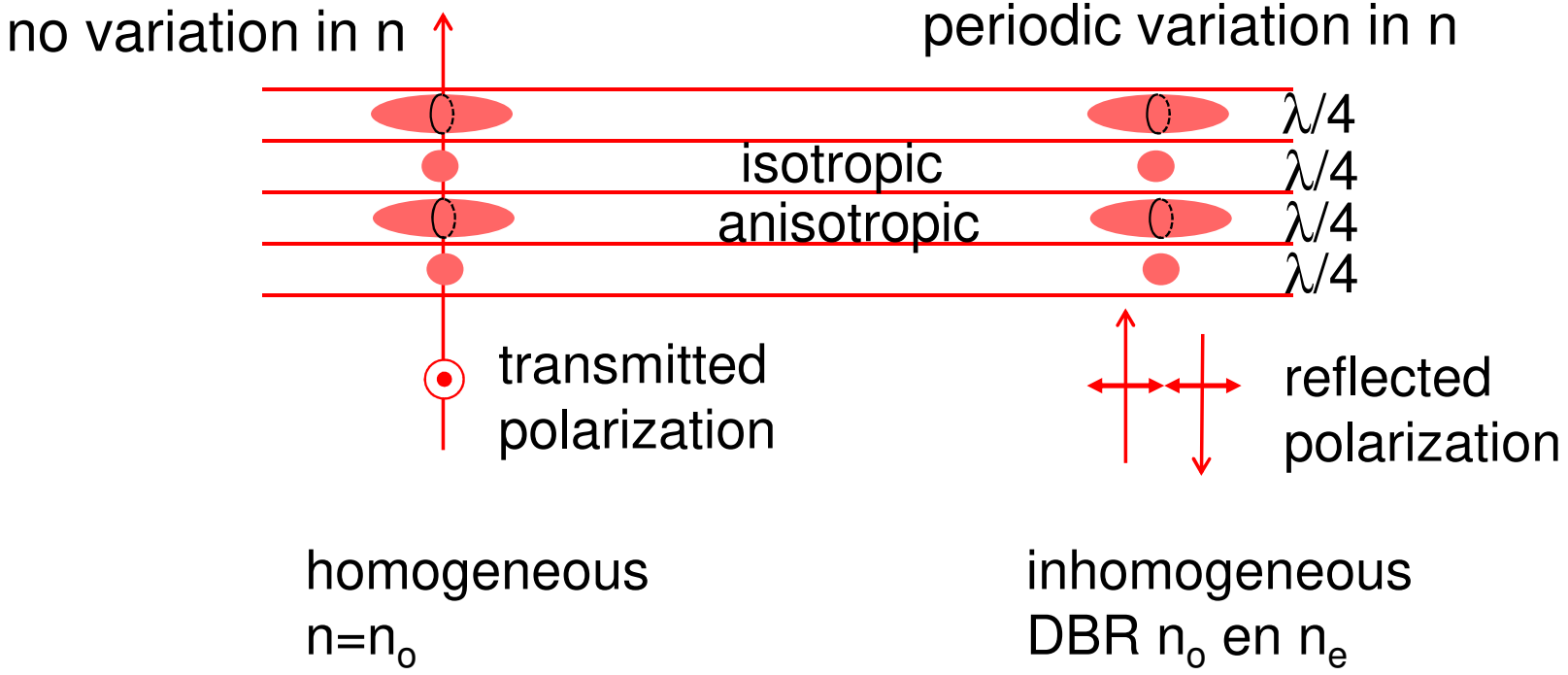
transmitted light is directed in the forward direction

BACKLIGHT AND OPTICS

Polarization recovery film (Dual Brightness Enhancement)

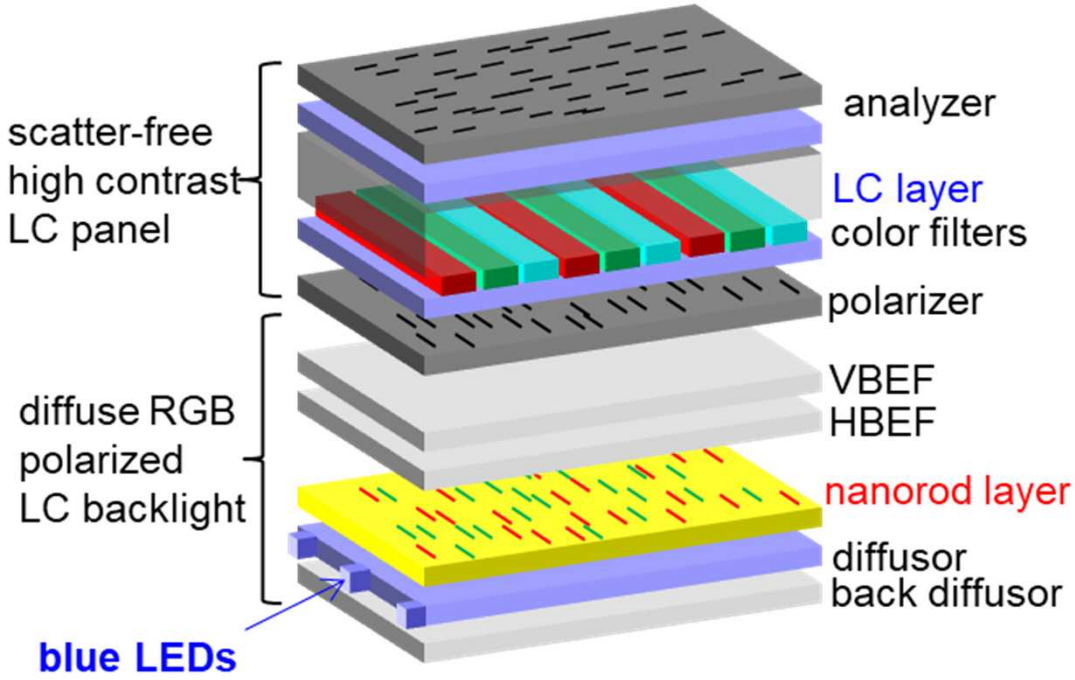
reflects the light with the wrong polarization (DBR)

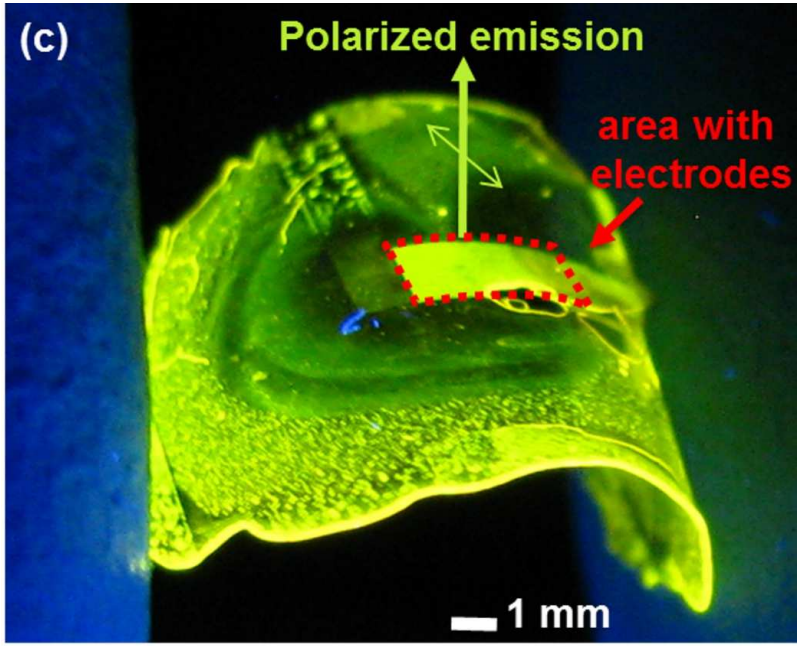
transmits the light with the appropriate polarization



BACKLIGHT AND OPTICS

Structure of LCD with polarized backlight





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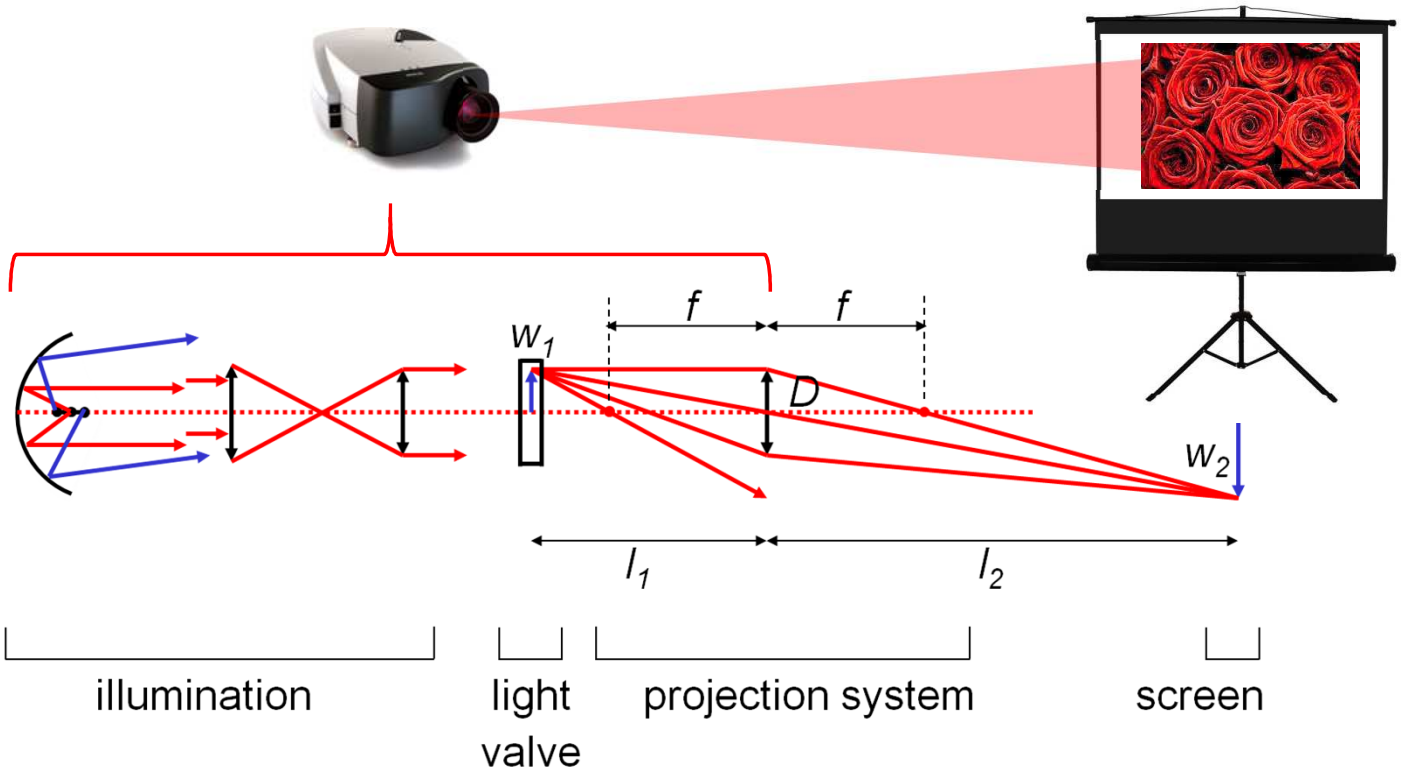
PROJECTION DISPLAYS

Technology based on a small light source and a large screen



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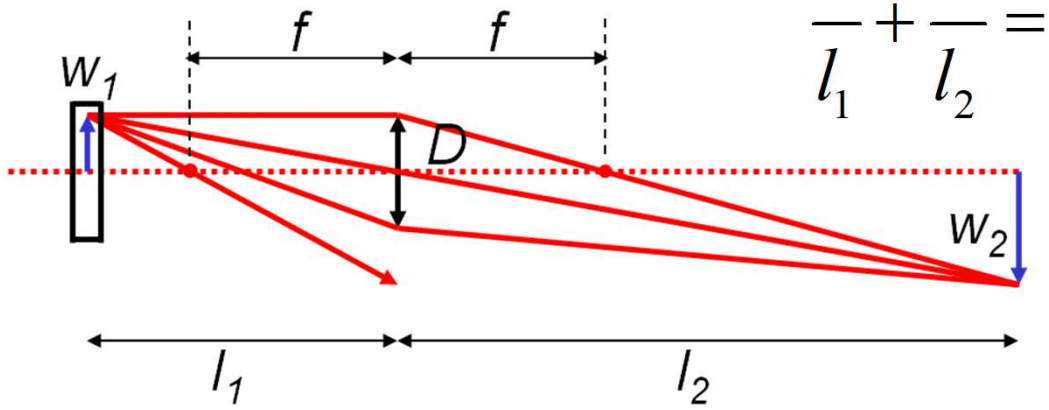
GEOMETRICAL OPTICS

Lens (focal length *f*): object and image distance

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



$$M=\frac{w_2}{w_1}=\frac{l_2}{l_1}=\ldots=\frac{1}{\frac{l_1}{f}-1}$$

large magnification *M* when $l_1 \sim f$

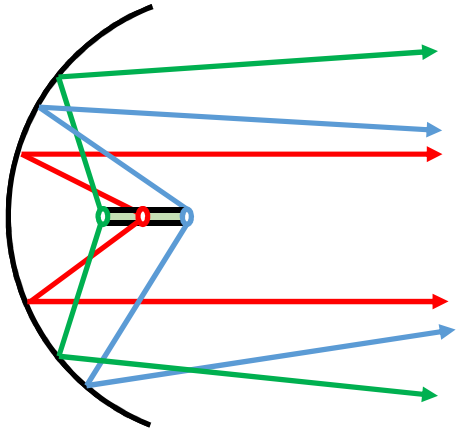
F-number of the lens: (sometimes called *f*/) $F=\frac{f}{D}$

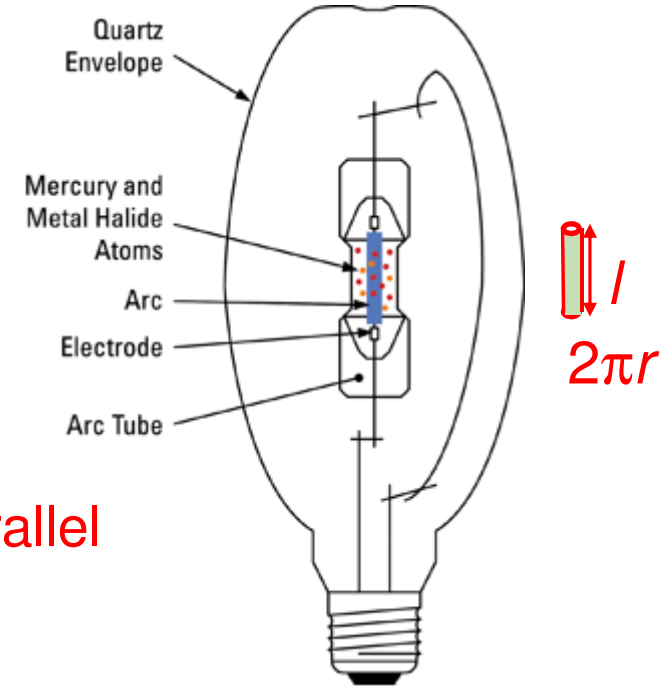
ILLUMINATION SYSTEM

high total flux (10 000 lumen) in a small étendue (π . $2\pi rl$)

high intensity discharge lamps (Xenon or UHP)

(discharge: current excites a gas in a small volume)





red rays: from the focal point: parallel

blue rays: slightly focused

green rays: slightly defocused

ILLUMINATION SYSTEM

Integrating rod to homogenize the light intensity

rectangular shape, area *A*, length *L*

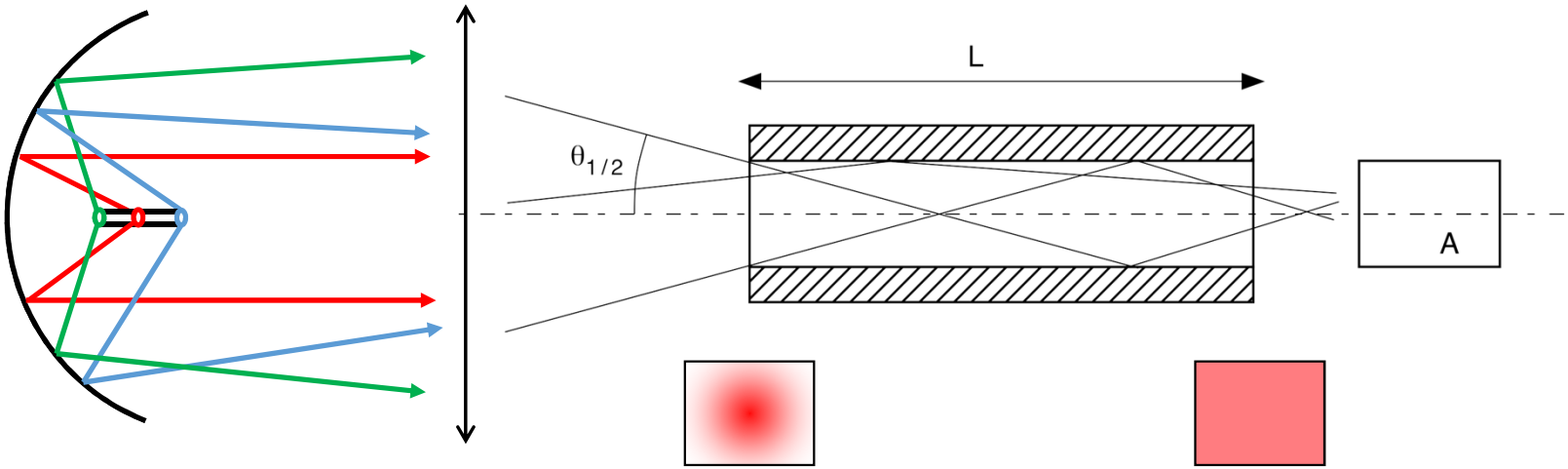
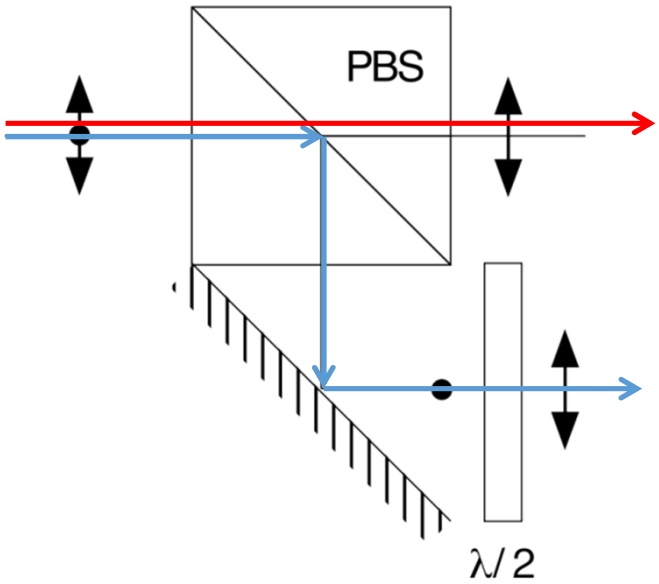


figure of merit: normalized length: $L_n = \frac{L \sin(\theta_{1/2})}{n\sqrt{A}}$

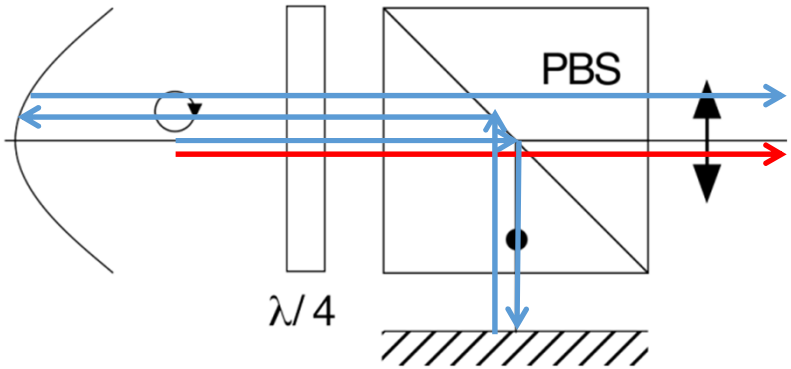
POLARIZATION CONVERSION

light with perpendicular polarization can be converted with a polarizing beam splitter (PBS)

with increase in étendue



without increase in étendue (through the light source)



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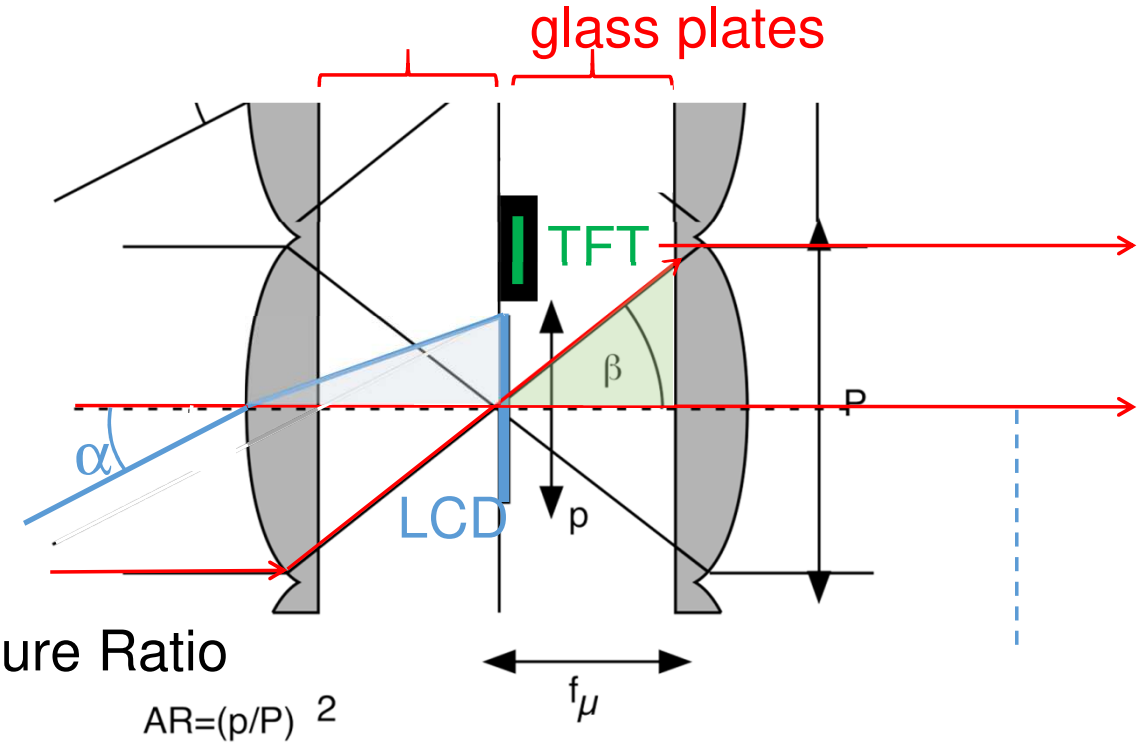
LIGHT MODULATION ENGINES: TNLCD

TNLCD uses polarized light

transistor: poly Si or crystalline Si with light shield

avoid the dark region by using lenses: aperture $p < P$



Aperture Ratio

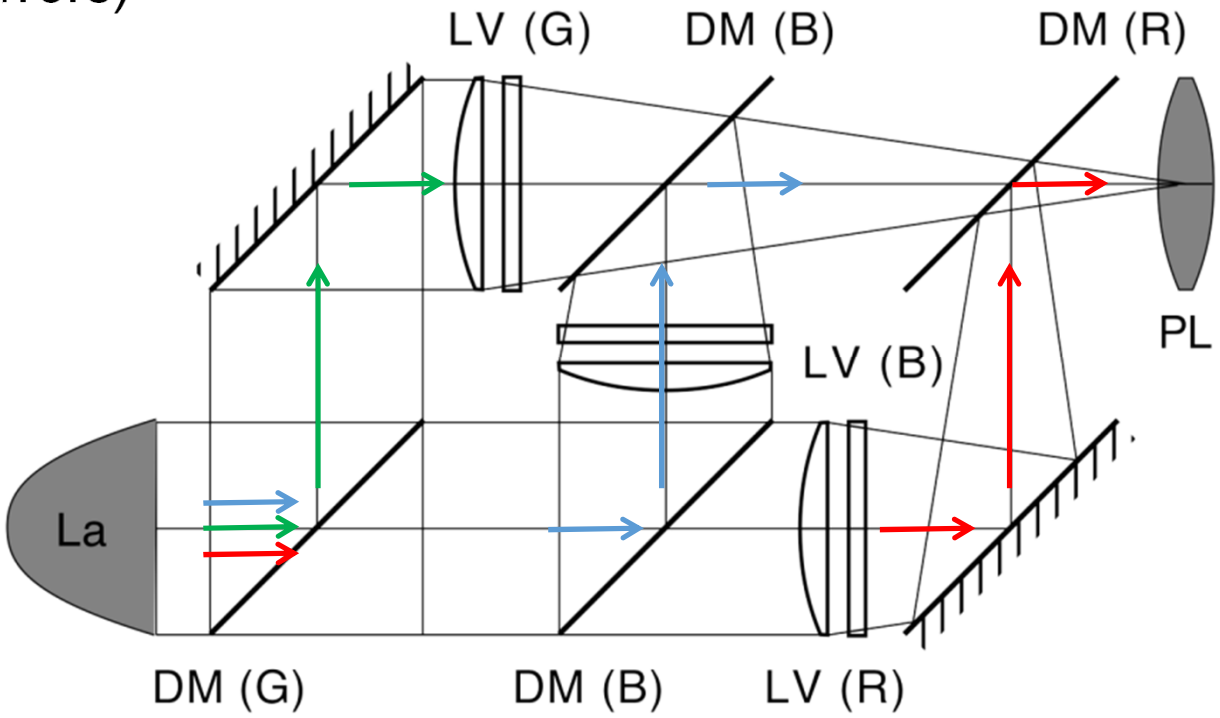
$AR=(p/P)^2$

SYSTEMS WITH THREE LIGHT VALVES

Most popular configuration

1 Lamp – 1 Lens – equal path length – Transmissive LC

(4 dichroic mirrors)



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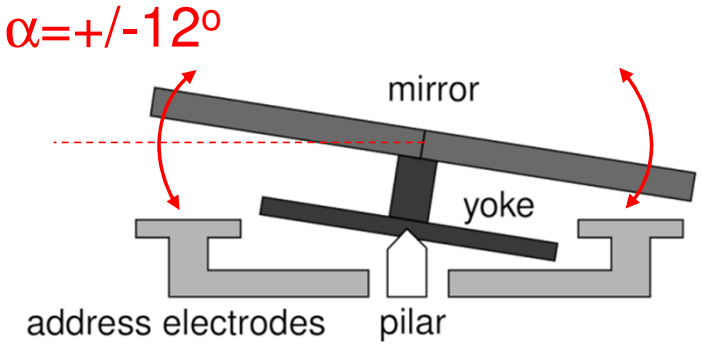
LIGHT MODULATION ENGINES: DMD

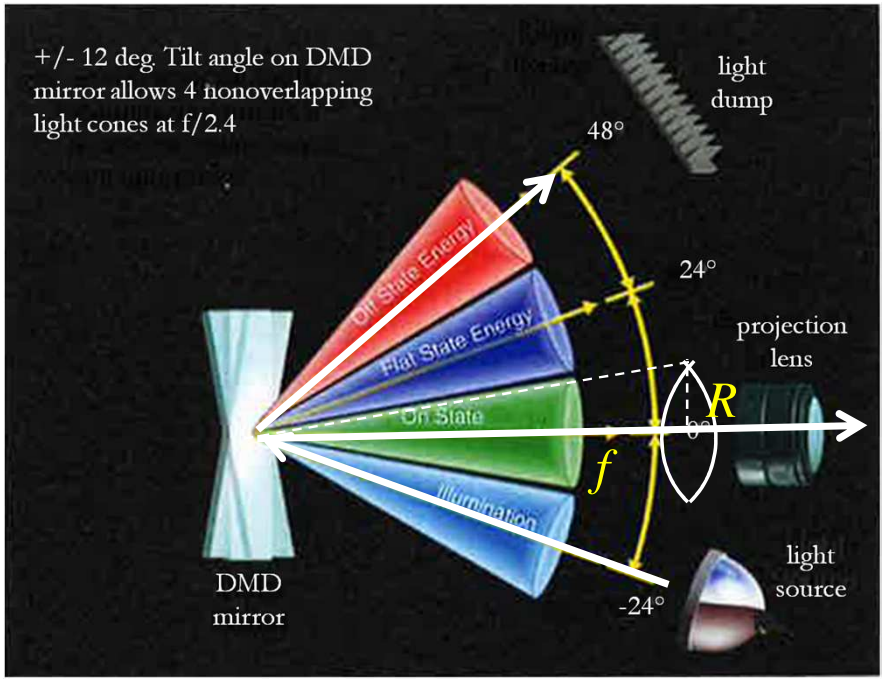
Digital Mirror Devices (DMD)

- micro-electro-mechanical mirror (Si MEMS), switch in 10 µs
- grey scale by ON-time modulation

$$F = \frac{f}{D} = \frac{f}{2R} = \frac{1}{2\tan\alpha} = 2.8$$



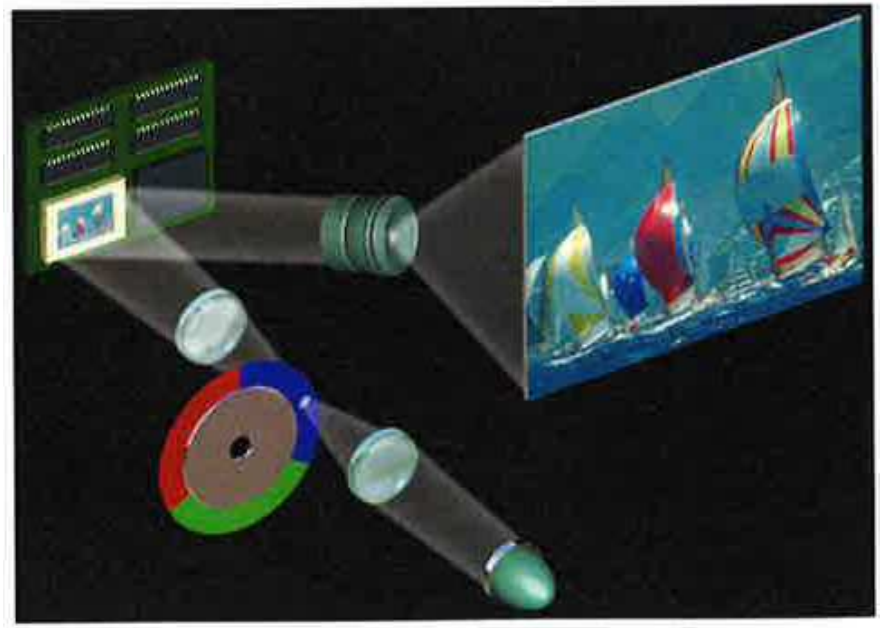
attracts when voltage applied



SYSTEMS WITH ONE LIGHT VALVE

RGB images are projected sequentially in time

- one light valve, color wheel for RGB (2/3 of light is lost)
- fast switching is required (between colors, grey scales)
- color separation with eye movement (rainbow effect)



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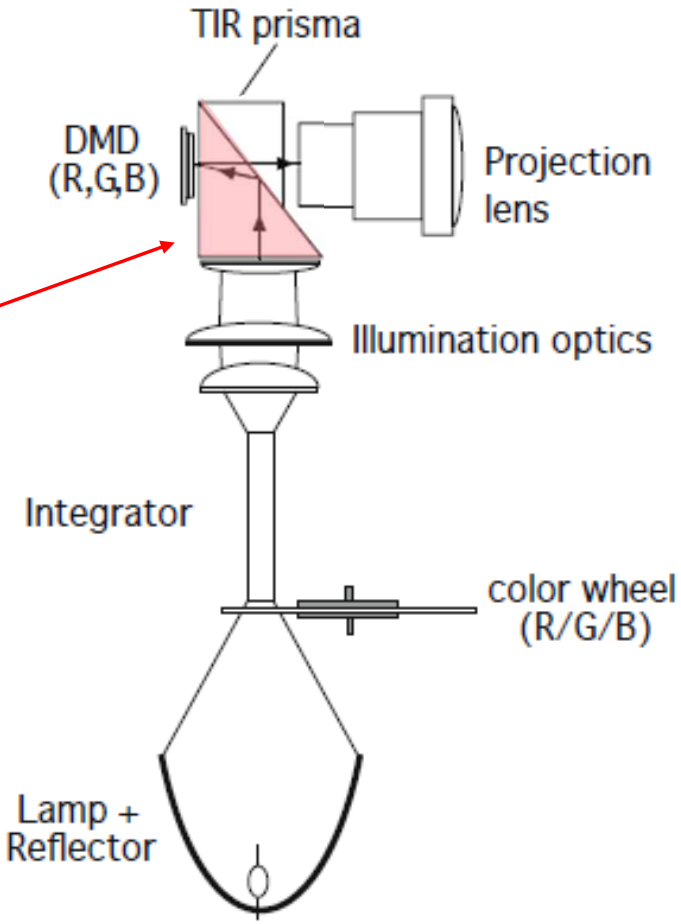
SYSTEMS WITH ONE LIGHT VALVE

Compact design
with a color wheel
and 1 DMD

TIR-prism
total internal reflection



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LIQUID CRYSTAL SWITCHING TIME

polymer network reduces the distance,

creating larger elastic torque, but also higher field needed