Liquid Crystal Displays

Wide Viewing Angle
High Dynamic Range

ELEN 4193
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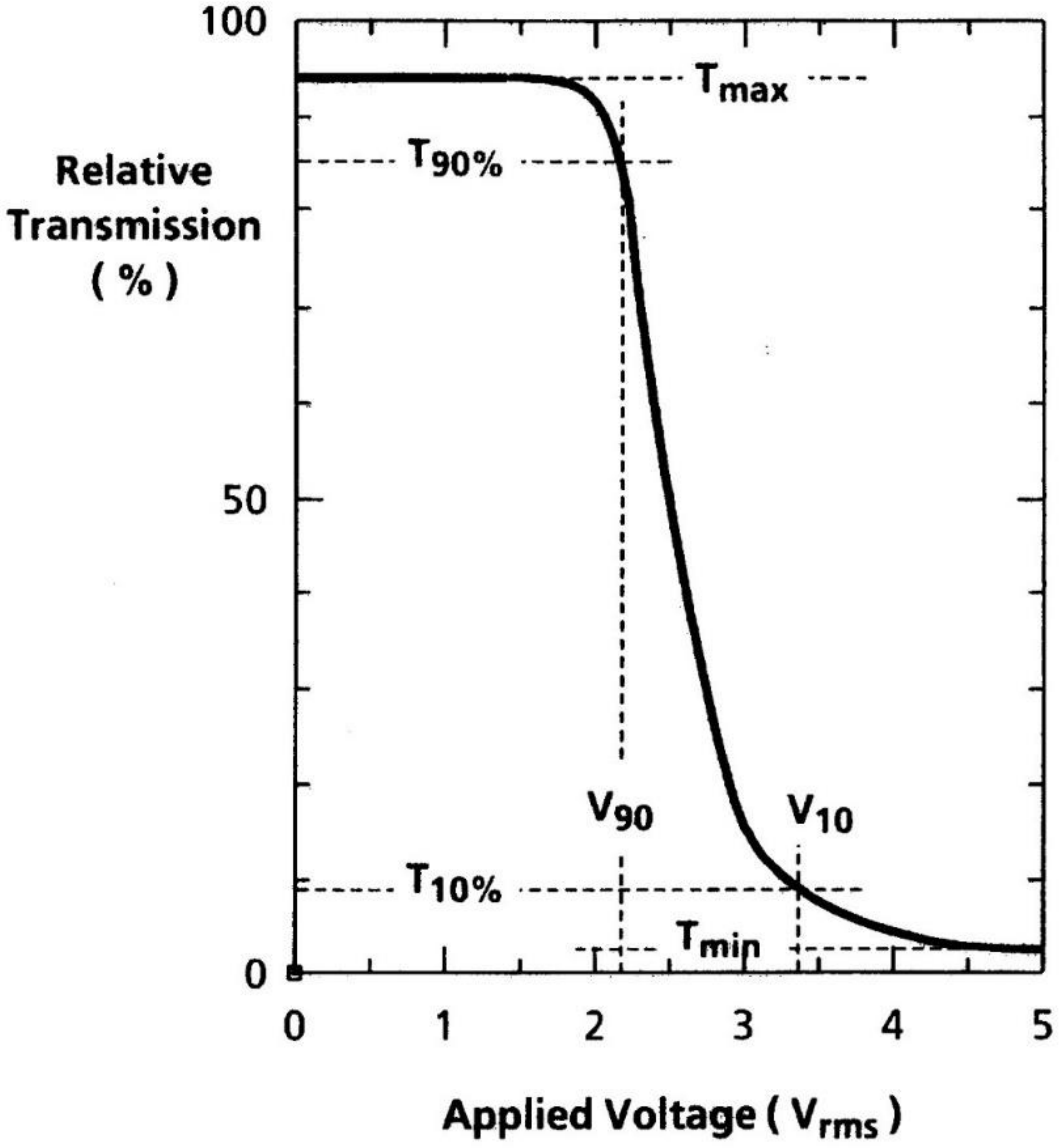
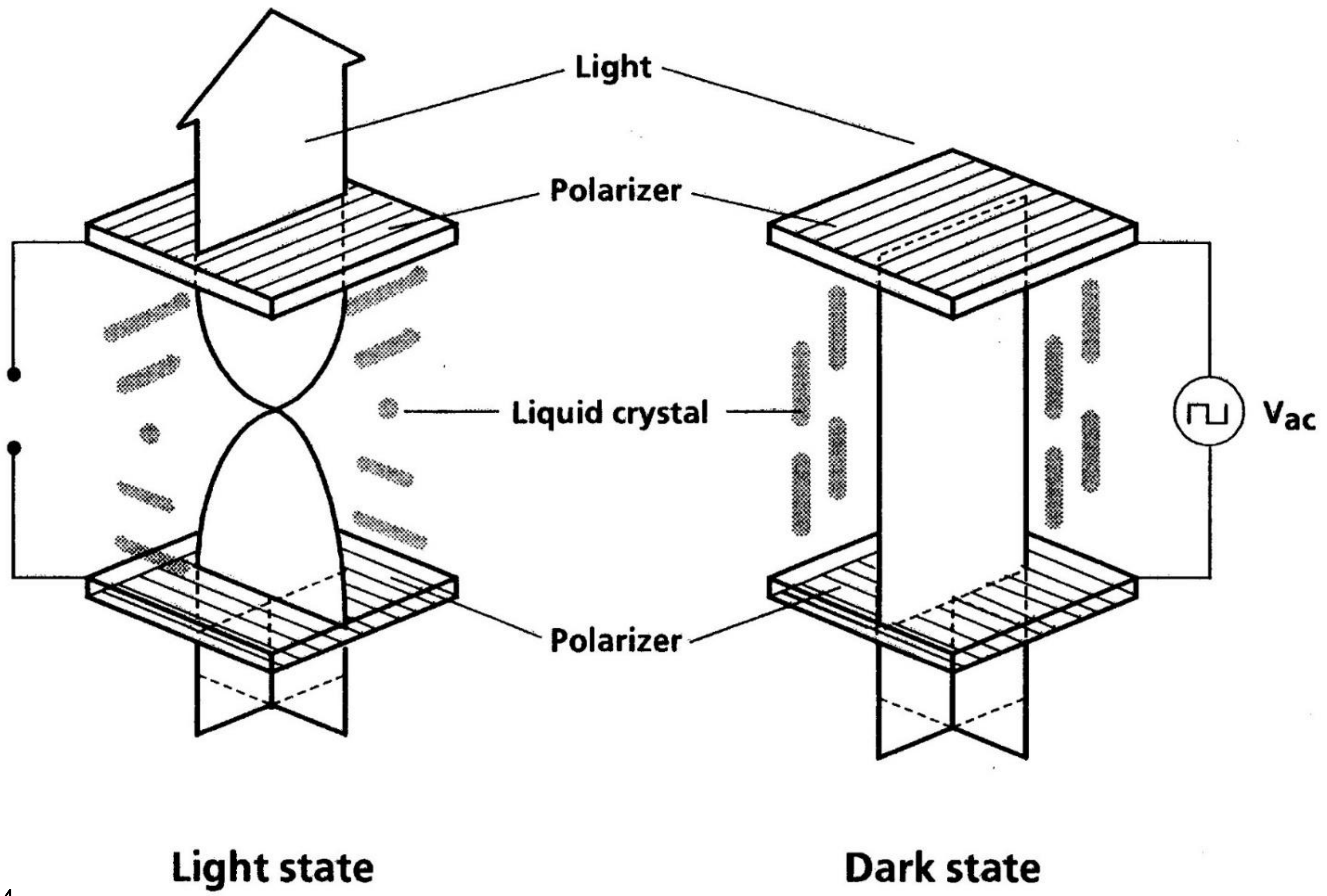
Adapted from John Kymissis

Where We Left Off…

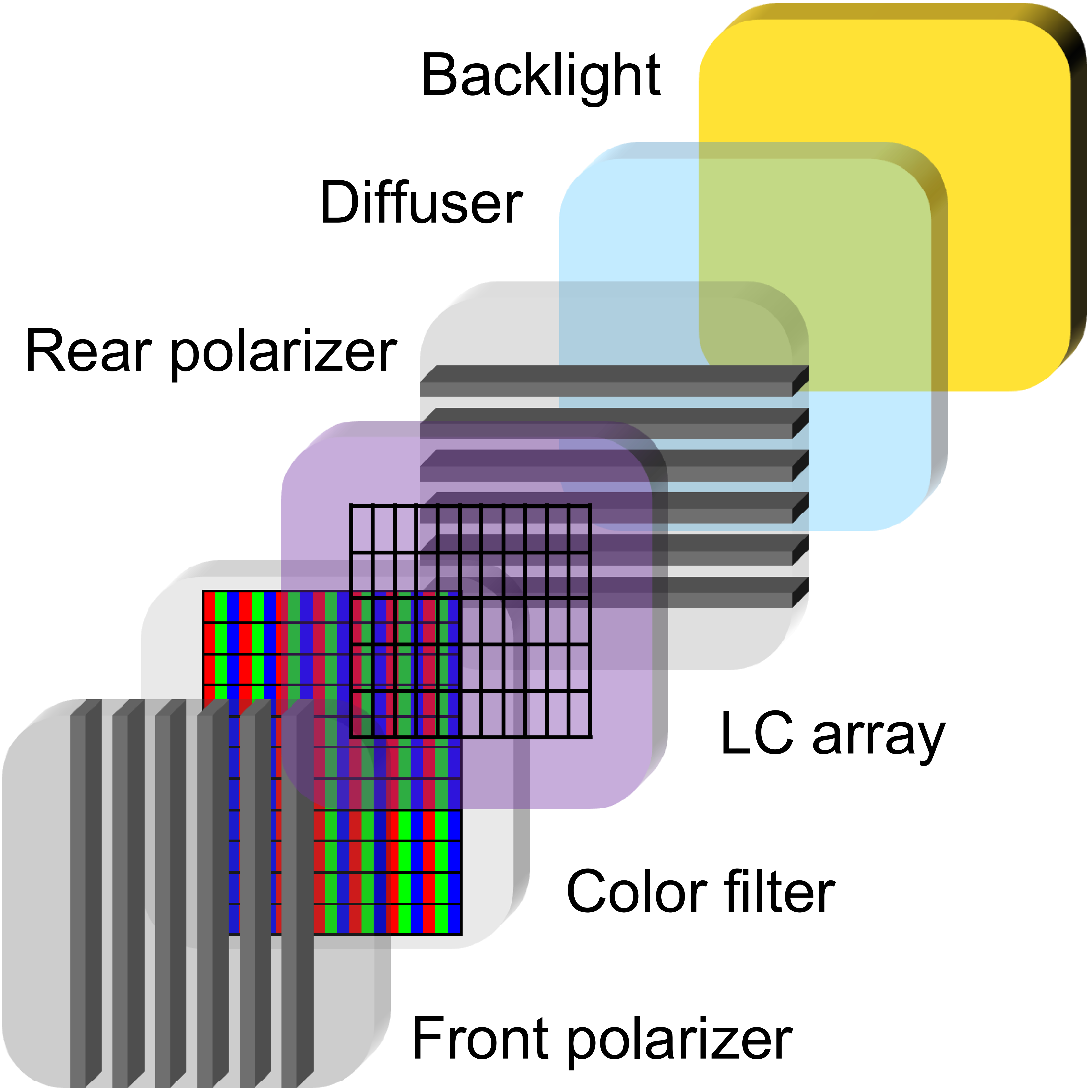


- This is a twisted nematic (TN) liquid crystal (LC) cell
- Applying field across the cell aligns the liquid crystal them → Rotates polarization of transmitted light
- AC field prevents build up of charge and burn in



Steemers, SID Seminar Notes 1994

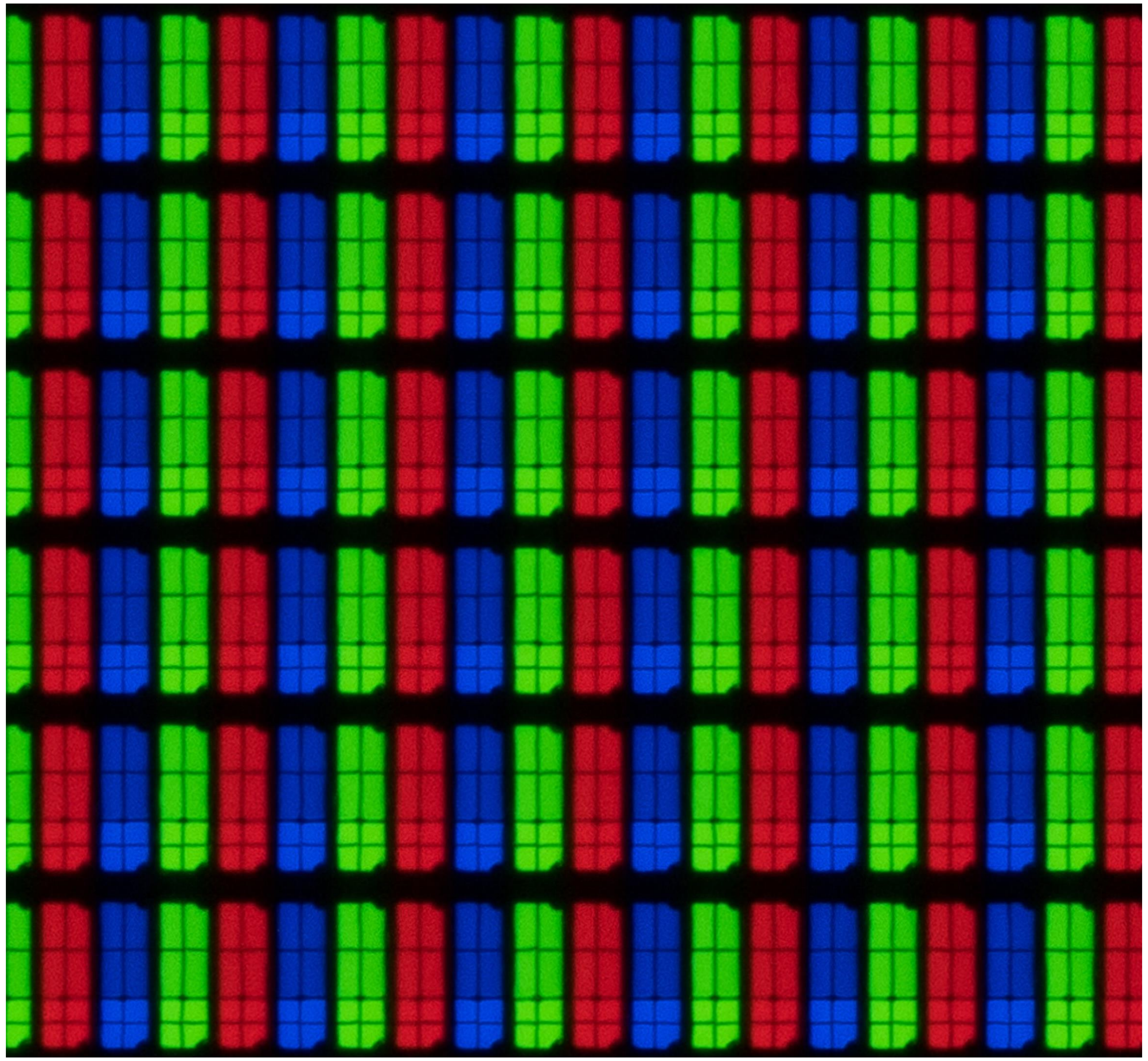
Making a Display



- Backlight globally emits white light at 100% luminance → Unpolarized
- Diffuser corrects non-uniformity
- Rear polarizer → Cuts vertically polarized component, passes horizontal
- LC array → At each pixel, choose whether to rotate polarization or not
- Color filter → At each pixel, filter out to R/G/B
- Front polarizer → Cut vertically polarized component → Only pixels which rotated the light emit

Concept of Transmissive Displays

- An LCD works in the opposite way that you might expect
- Each subpixel is not an individual *light emitter*
- Instead, they are *light blockers*
- The LCD is acting as a "spatial light modulator" → It take existing light and modulates it to create a pattern
- Displays of this type are typically called "transmissive" (as opposed to "emissive")



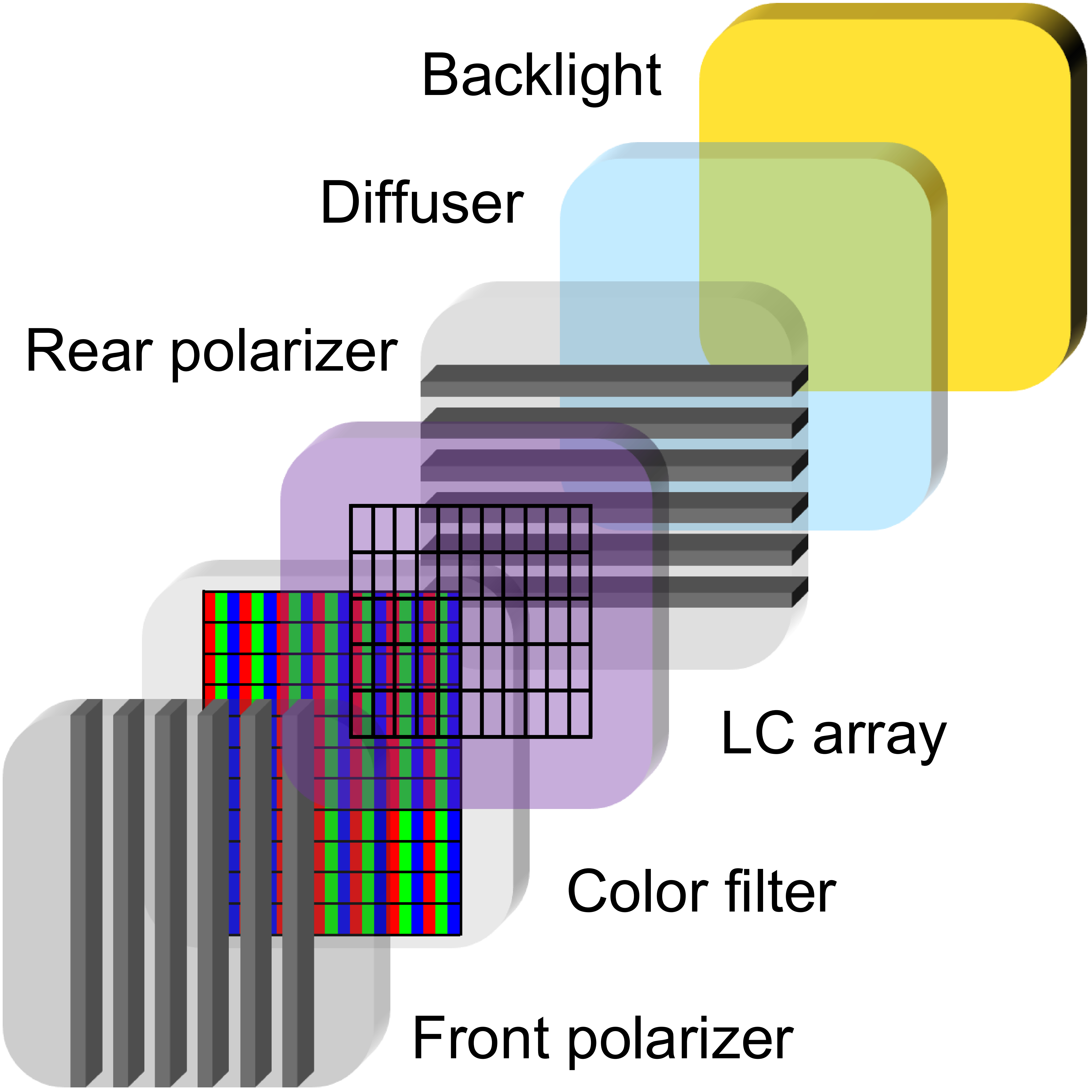
LCD Pixels from a Vizio TV - Credit: rtings

LCD Efficiency

Let's think about efficiency…

- Backlight → Let's say it's **100%** efficient
- Diffuser → Some scattering, **≈90%** transmission
- Horizontal polarizer → Cut vertical light, **50%** transmission
- LC array + Vertical polarizer → Let's assume image is white at mid gray level, **50%** transmission
- Color filter → Filter out 2/3 of R/G/B, **33%** transmission

$$T \approx 1 \times 0.9 \times 0.5 \times 0.5 \times 0.33 \approx 7\%$$



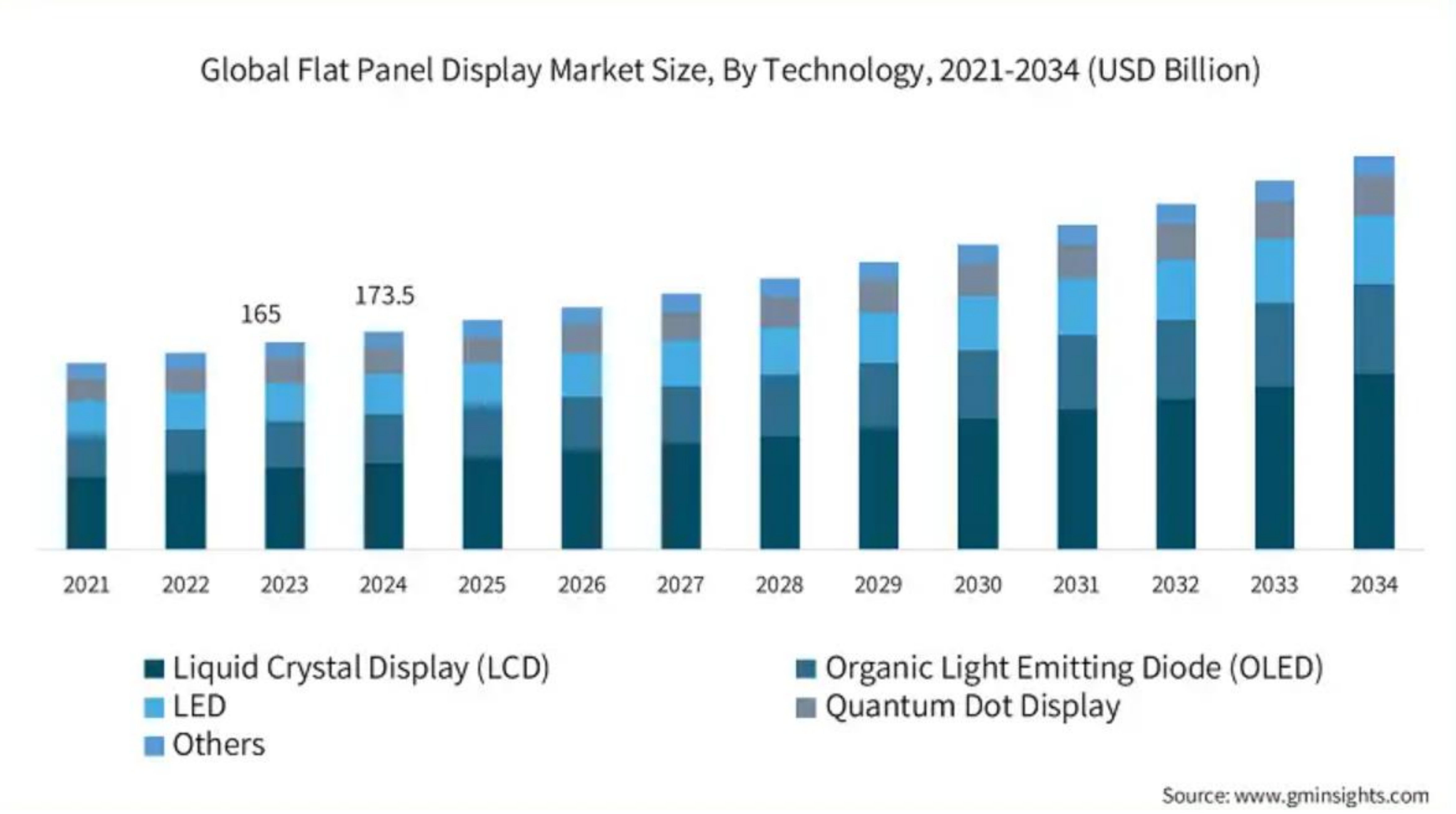
LCD Efficiency

$$\boxed{\eta \approx 1 \times 0.9 \times 0.5 \times 0.5 \times 0.33 \approx 7\%}$$

- This is terrible!
- And it doesn't even take into account backlight efficiency, fill factor, light extraction, etc.…
- There is content dependence
- Lower gray levels → Lower efficiency
- Single primary colors → Lower efficiency

LCD Economy

- Despite this, LCDs have dominated the display market
- Manufacturing: very mature, cheap to fabricate at very large scale
- Reliability: no burn-in issues, lifetime on the scale of 5-10 years of continuous operation
- Timing: LCD tech arrived at the right time, beat OLED to the punch for early flat panels

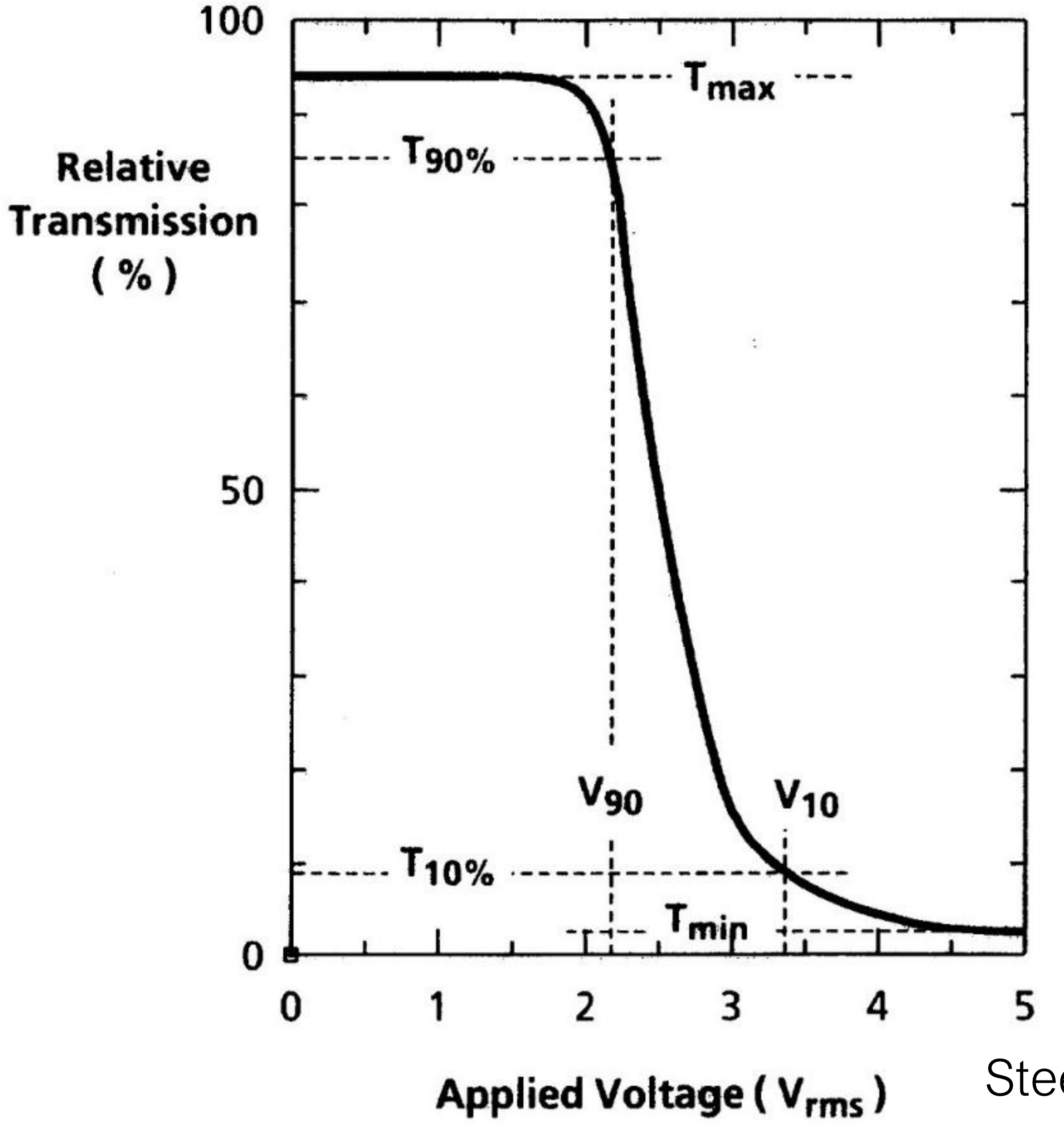


Display market size by panel type - Credit: Global Market Insights

Challenges with LCD

- For the rest of the lecture, we'll discuss challenges with improving LCD performance
- Improving viewing angle
- Improving contrast
- Focus improvements from the last ~decade to now

LCD viewing angle - Credit: LG Display Newsroom

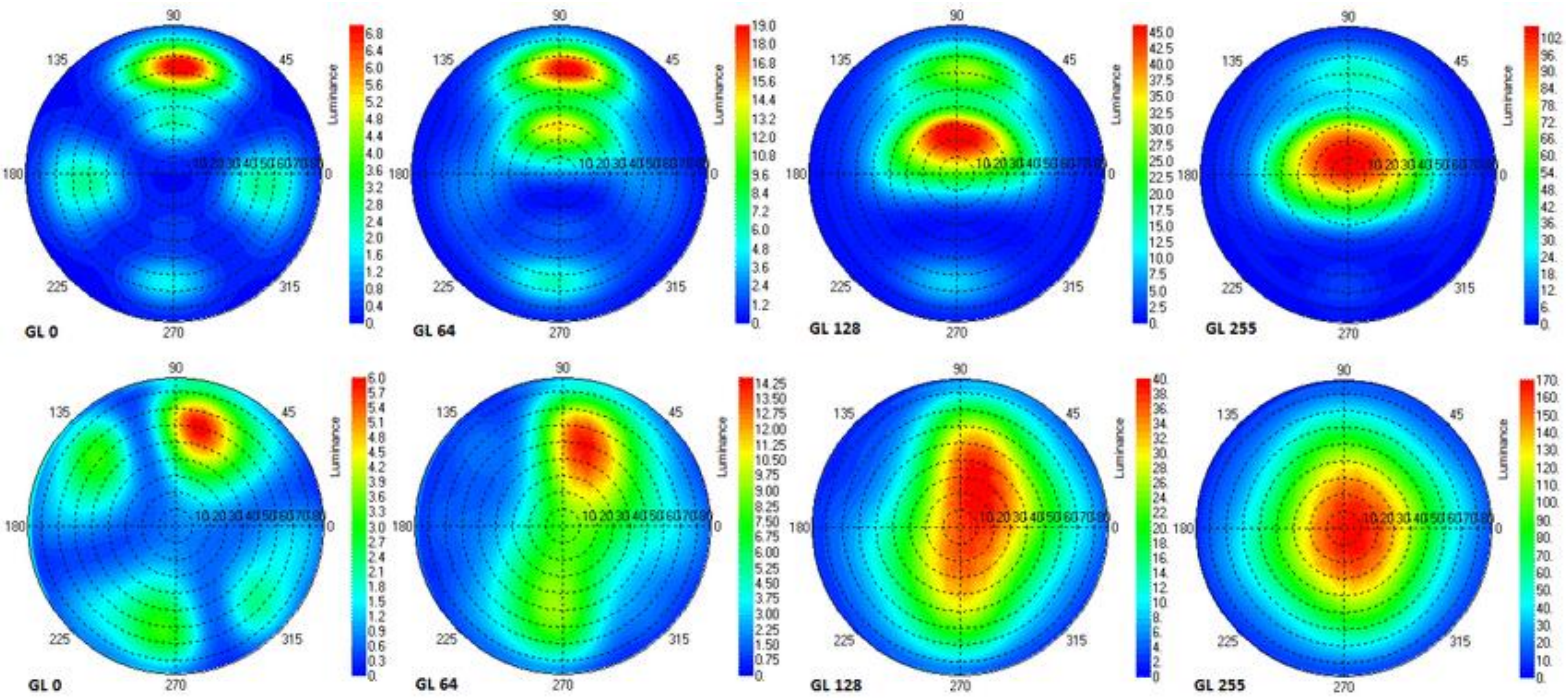


- V_{10}, V_{90}
- Contrast ratio = T_{max} / T_{min}
- Gray scale

Steemers, SID Seminar Notes 1994

TN-LCD Viewing Angle

Luminance depends on viewer's location…. And the dependence is a function of gray level…



Boher, Pierre, Thierry Leroux, and Thibault Bignon. "Viewing angle and response time behavior of LCDs versus temperature."

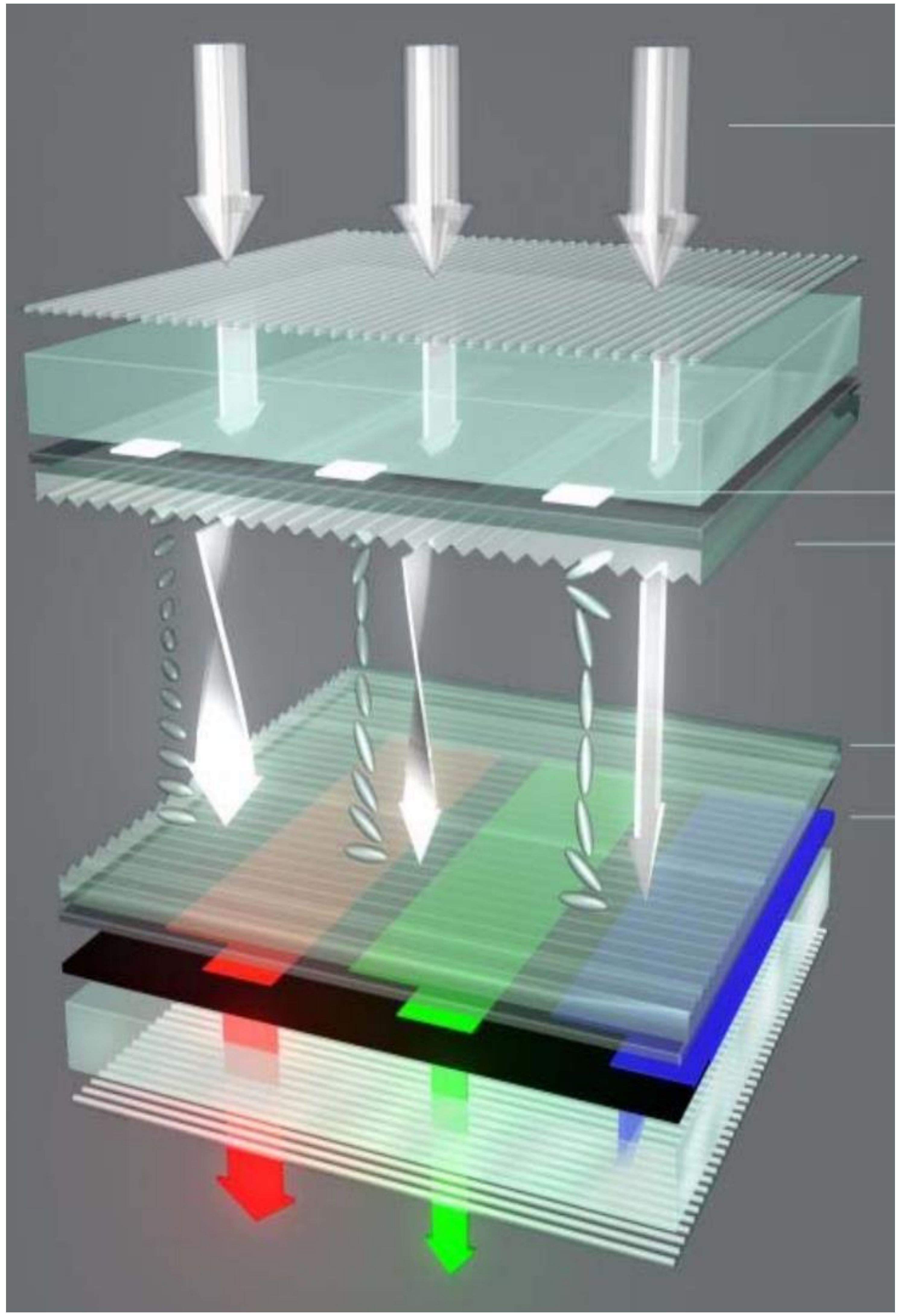
Wide Viewing Angle

- **Off axis behavior of polarizers** → Polarizers leak when light is not normally incident

- **Asymmetry of TN LCD** → Off-normal light sees oppositely tiled molecules

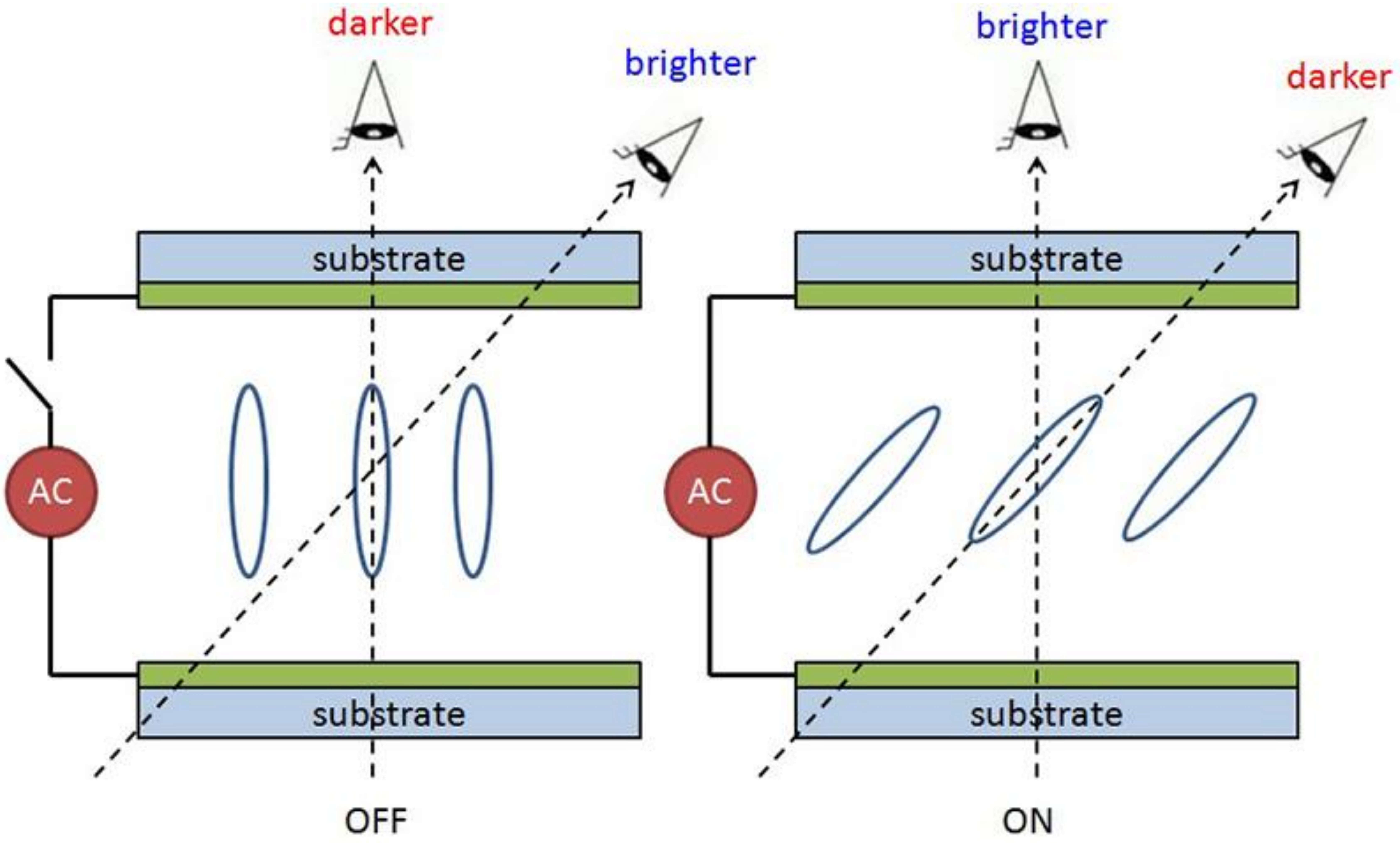
- **Pre-tilt** → Leads to asymmetry depending on which side of the tilt axis the viewer

- **Variable path length** → Off-normal light has a longer path length through the LCs, changes phase rotation and finally transmission.



Credit: Merck KGaA, Darmstadt, Germany

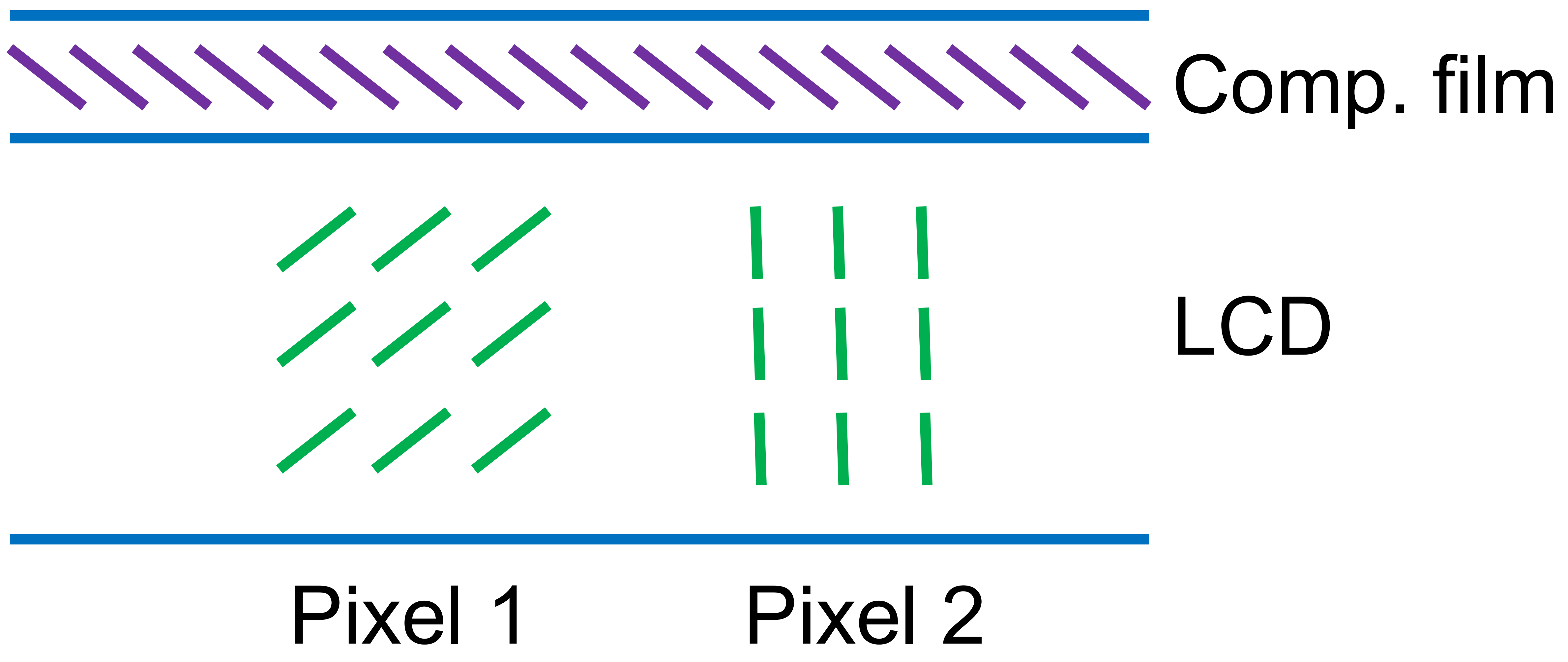
Asymmetry



Contrast inversion - Credit: Winstar

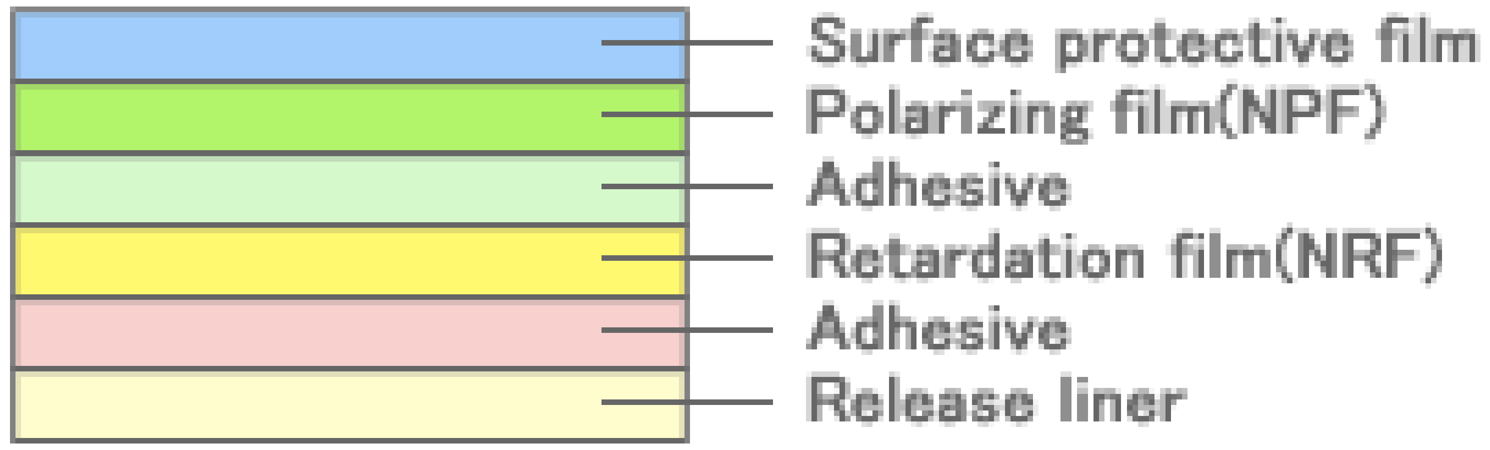
Compensation (a-plates, c-plates)

- These are waveplates that pre-compensate for the polarization difference
- They are typically created from a class of materials called reactive mesogens
- They function as essentially a static LCD
- **Take home:** the plates average out the amount of rotation the light gets so remove angle dependence
- Films like these can compensate pre-tilt, asymmetry, path length difference…

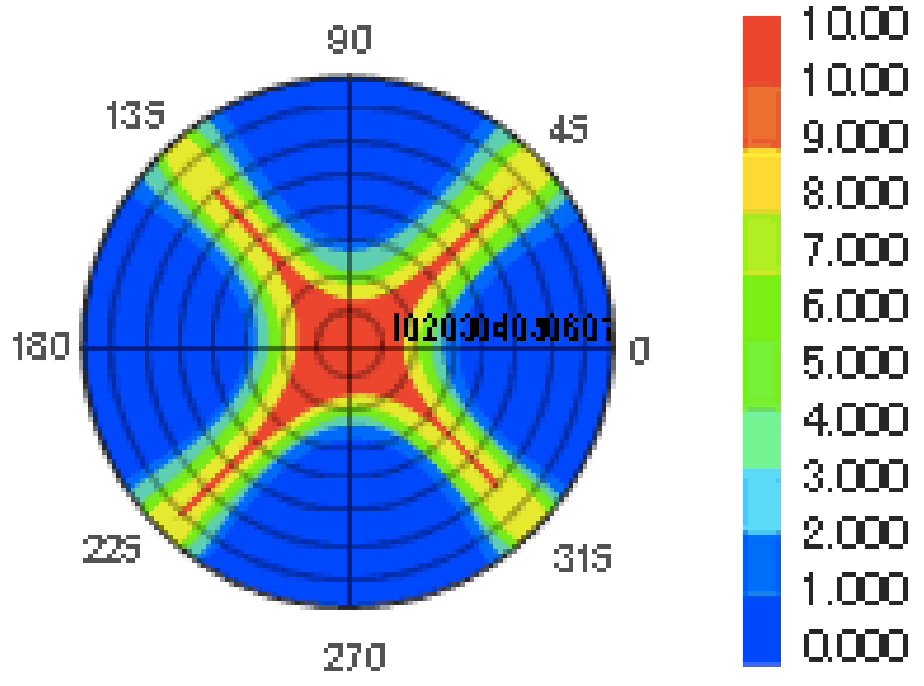


Who Makes These?

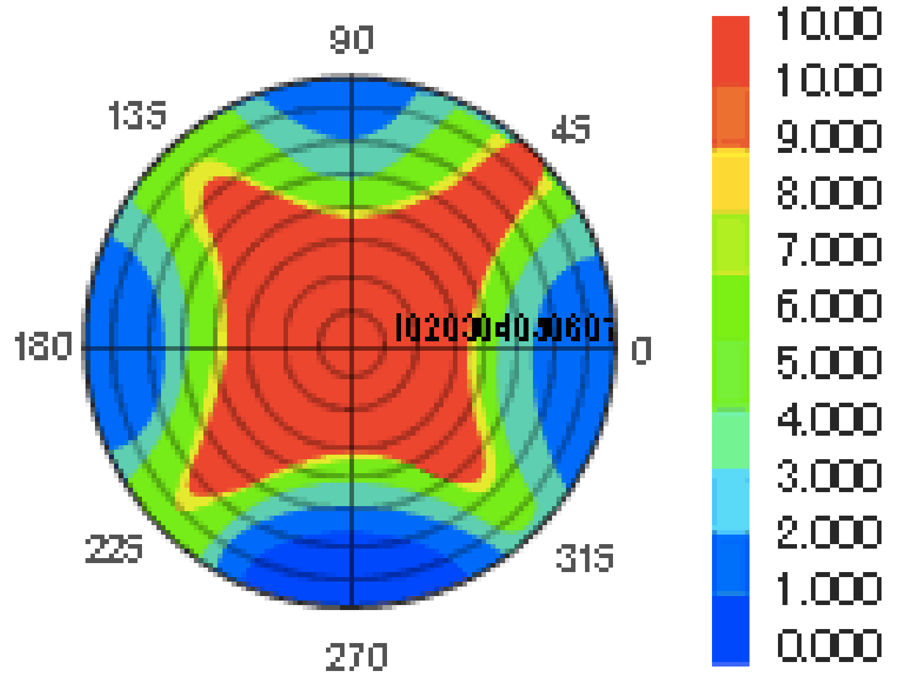
- These are actually pretty big business
- Because they enable higher performance LCDs
- Fujifilm, Nitto, 3M…



Before

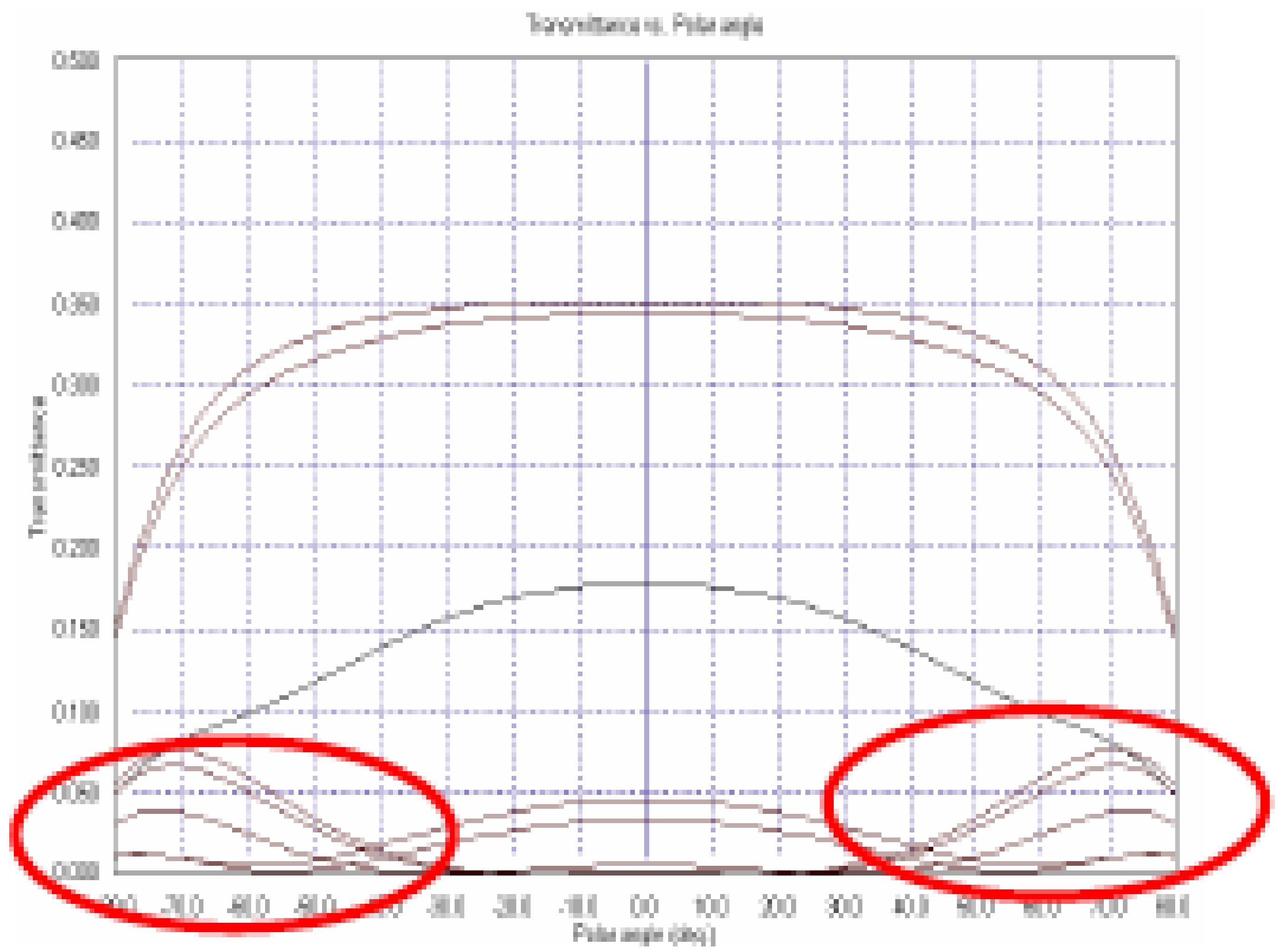


After

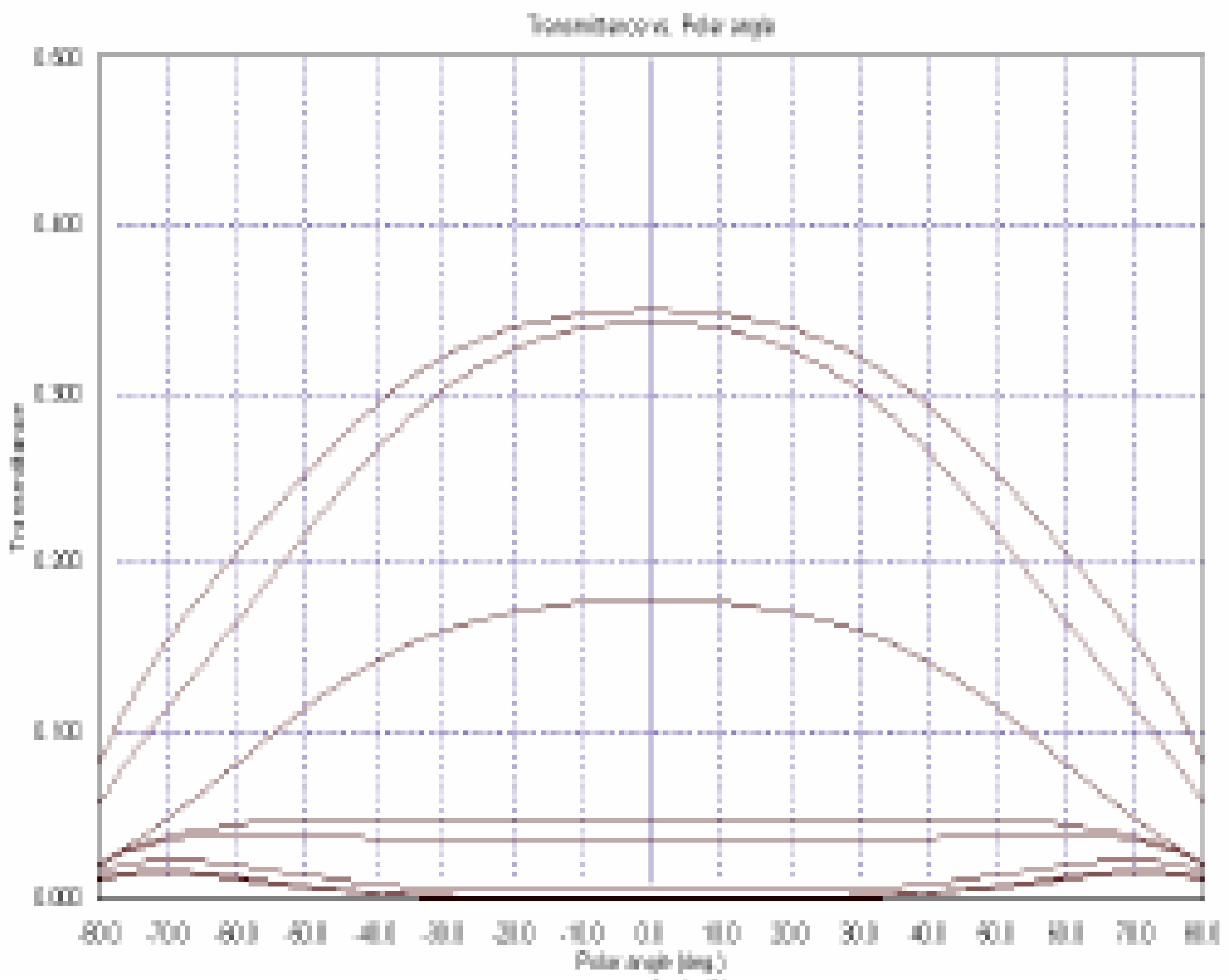


Impact on Viewing Angle

Different grayscale vs viewing angle



TN



TN+ Fuji WV film

New Modes of LCD

- Several new types of liquid crystals have been developed to improve on TN
- In-Plane Switching (IPS) → Pioneered by RCA, taken over by Hitachi, LG licensed from them
- Samsung was not granted the right to license the IPS patents, so…
- Vertical Alignment (VA) → Developed by Fujitsu, licensed by Samsung
- Today, all of the foundational patents are expired
  - Anyone can use whichever they want
  - A lot of new innovation

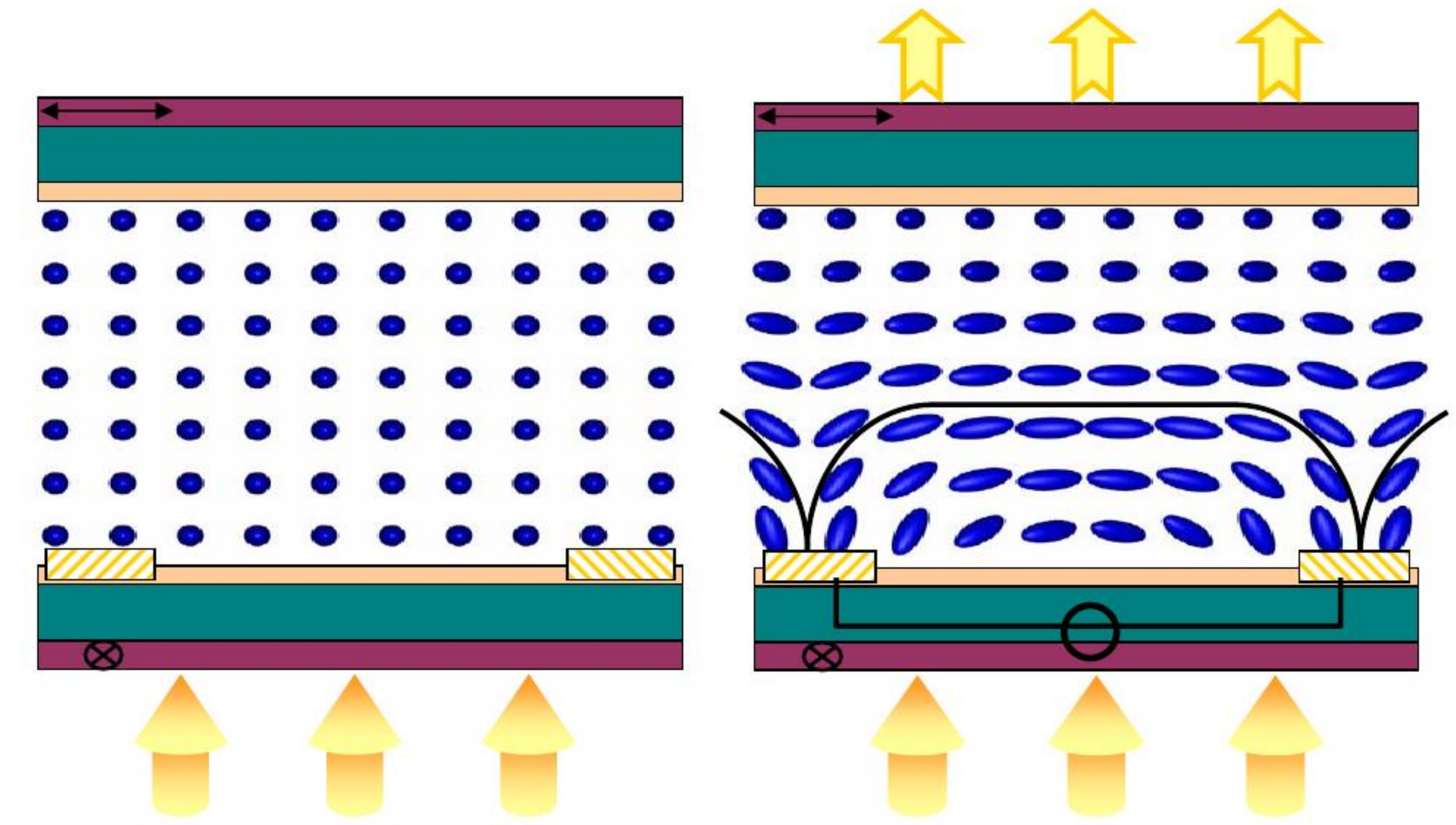
IPS Concept

- Instead of trying to move the LC vertically, rotate it in the plane of the substrate

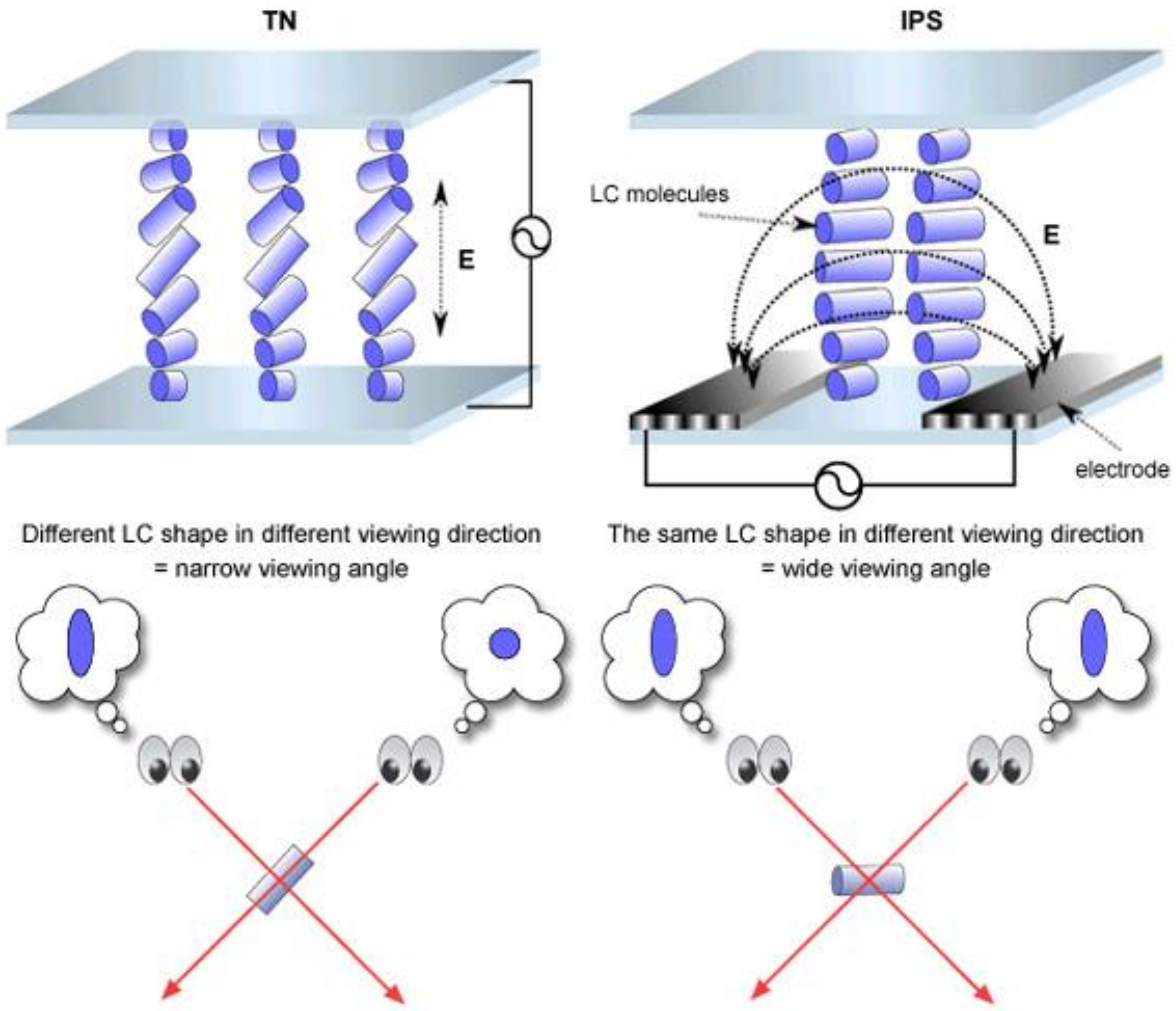
- Using this, we can achieve the same kind of switching effect as in TN

- The big win here: can be made much more symmetric than TN, especially with multiple electrodes

- Nothing really, happens right above the electrode, but that mostly fine (costs a little bit of fill factor)



Symmetry in IPS



Credit: Chee-Mei, Innolux

IPS Branding

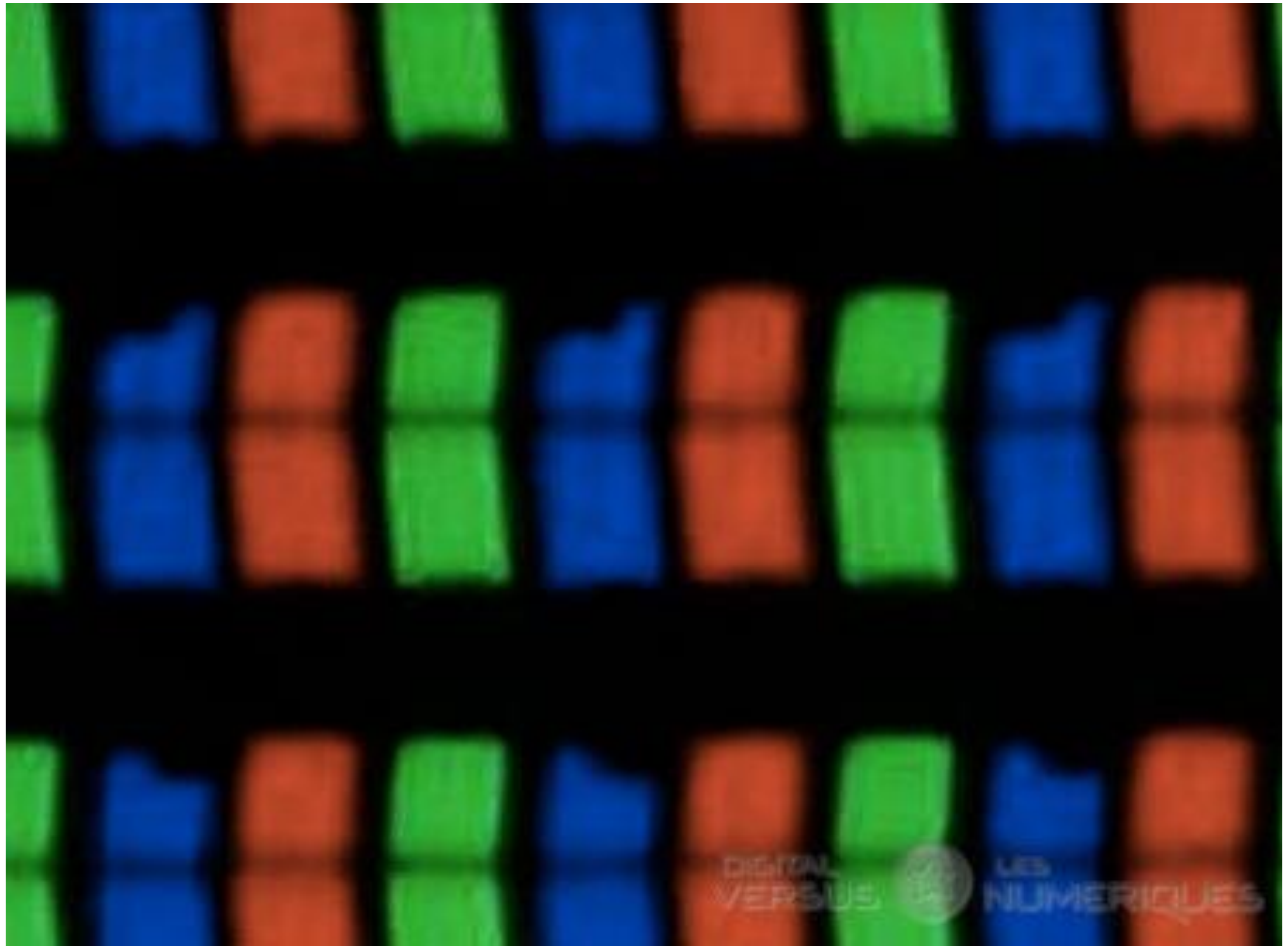
量産開始年	S-TFT（1996年） 世界初広視野角	S-IPS（1998年） 高画質化	AS-IPS（2002年） 高輝度化	IPS-Pro（2004年4Q~） 高コントラスト化
液晶画素写真				
透過率（相対値）	100	100	130	156
コントラスト	100	137	250	313

Credit: Hitachi

- People love coming up with new brand names for this..
- Black area between pixels → No LC rotation at electrode
- Tilted pixels → Increases viewing angle homogenization… angle depend on whether up/down or left/right is more important

Samsung "PLS"

- Samsung was initially blocked from using IPS…
- So they invented their own version which is essentially the same, but IP-clean called PLS
- Older generation MacBook Pros used this, but patents expired ≈ 10 years ago
- So now they just call their panels IPS, too



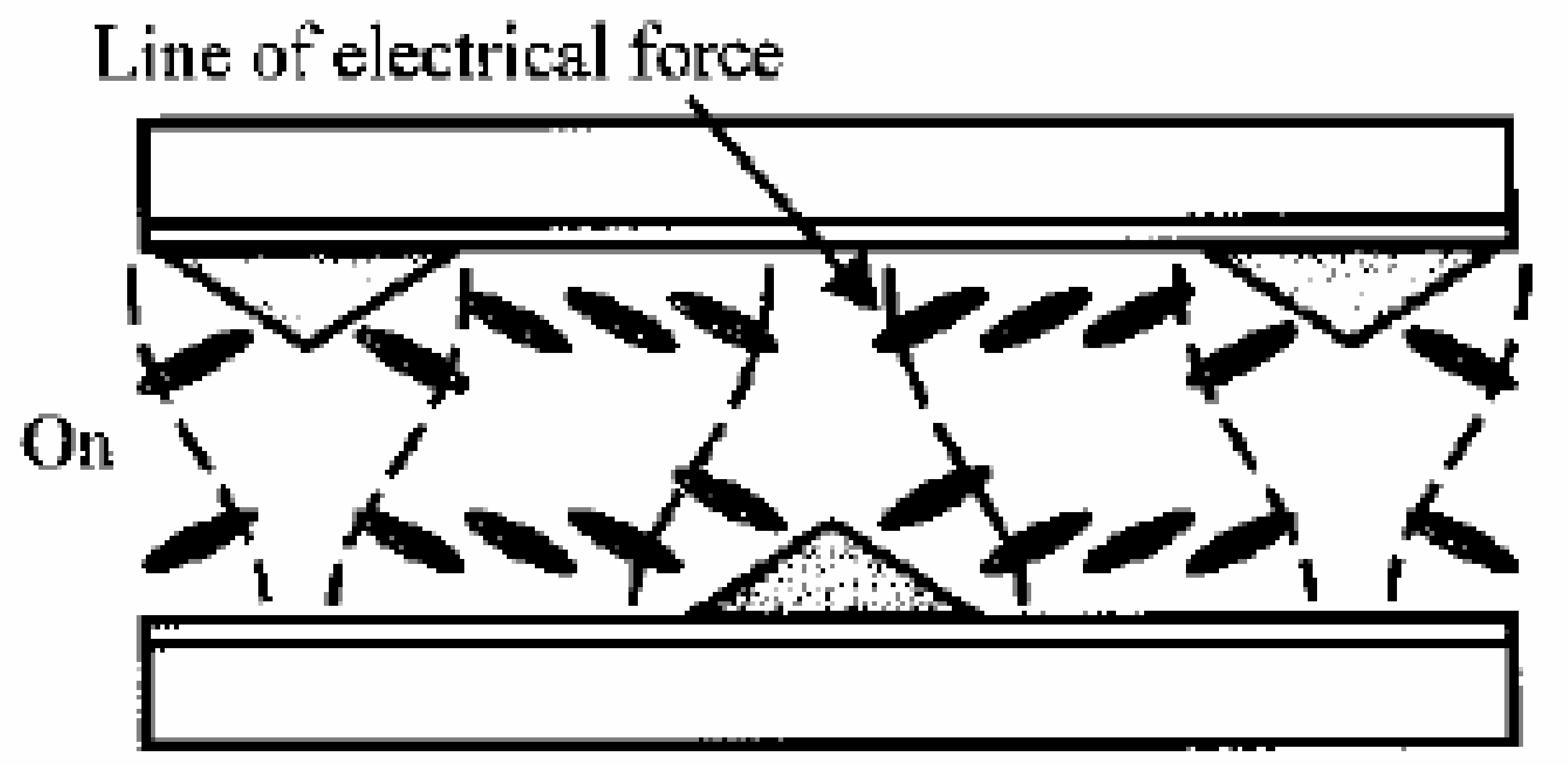
Credit: DigitalVersus MacBook Pro Sneak Peek

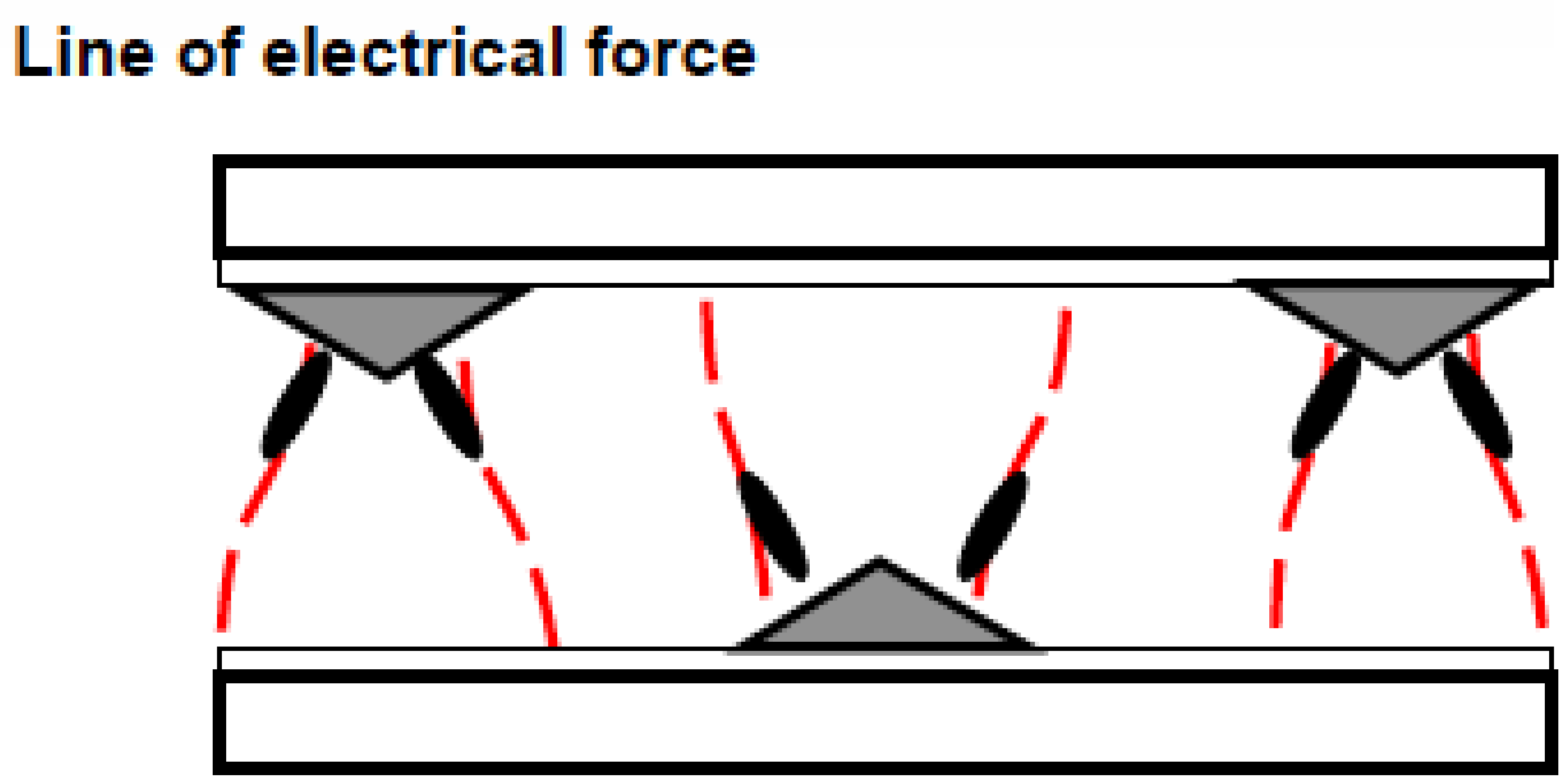
IPS Advantages

- Better viewing angle
- More homogeneous color
- Totally planar (no physical protrusions) → Simpler fabrication

Concept of Vertical Alignment

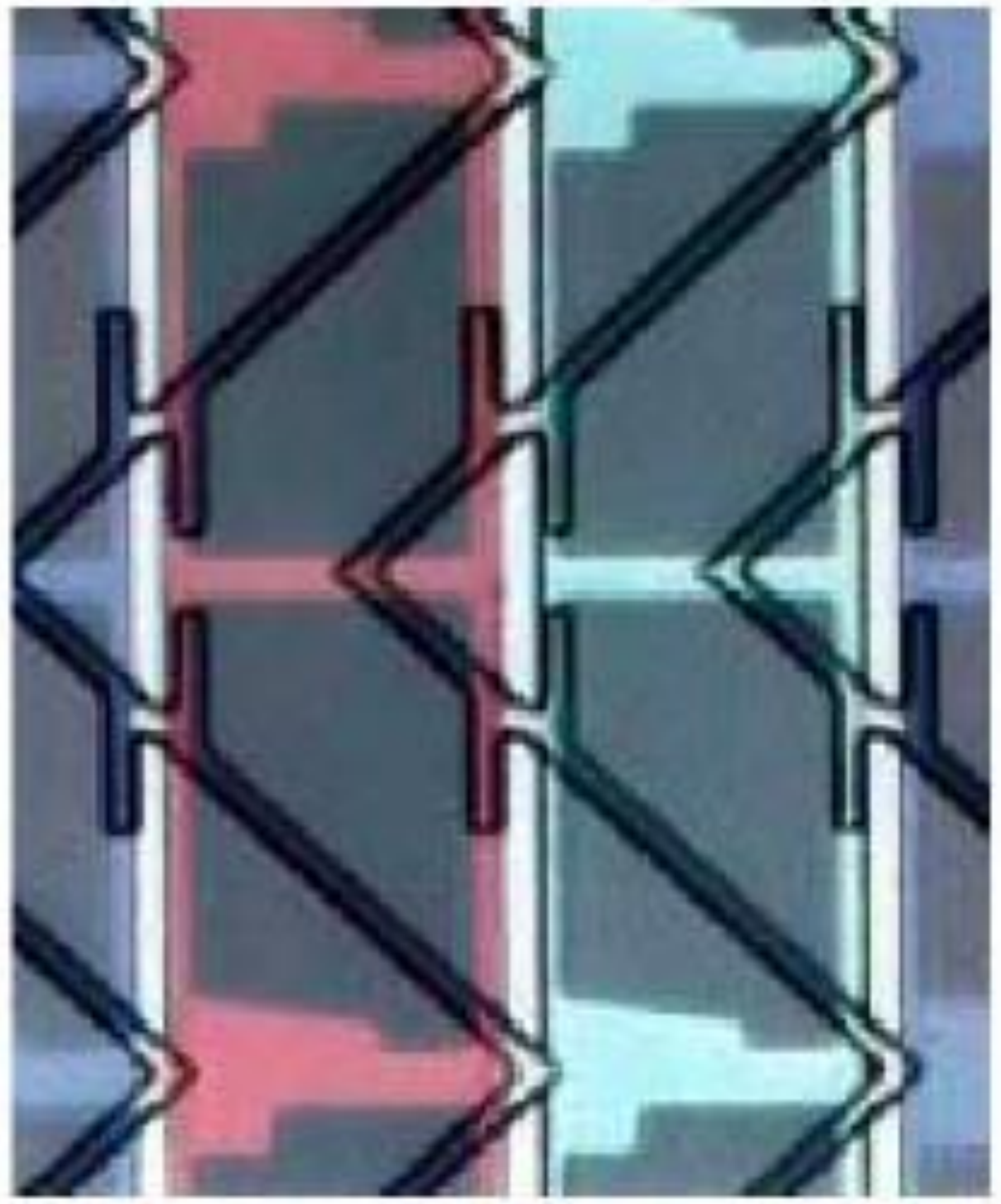
- VA was developed primarily by Samsung
- Similar result to IPS, but instead it uses a patterned substrate and staggered electrodes
- Basic idea:
  - Protrusions in the substrate give the LCs a template, so they are already tilted
  - Using the staggered electrodes, rotate them in any desired direction
- Achieves the same kind of rotation as IPS, but electrodes are top/bottom instead of in the same plane → IP-clean
- Because mechanism is similar, same pros (better symmetry) and cons (black out electrode, also complex fab)

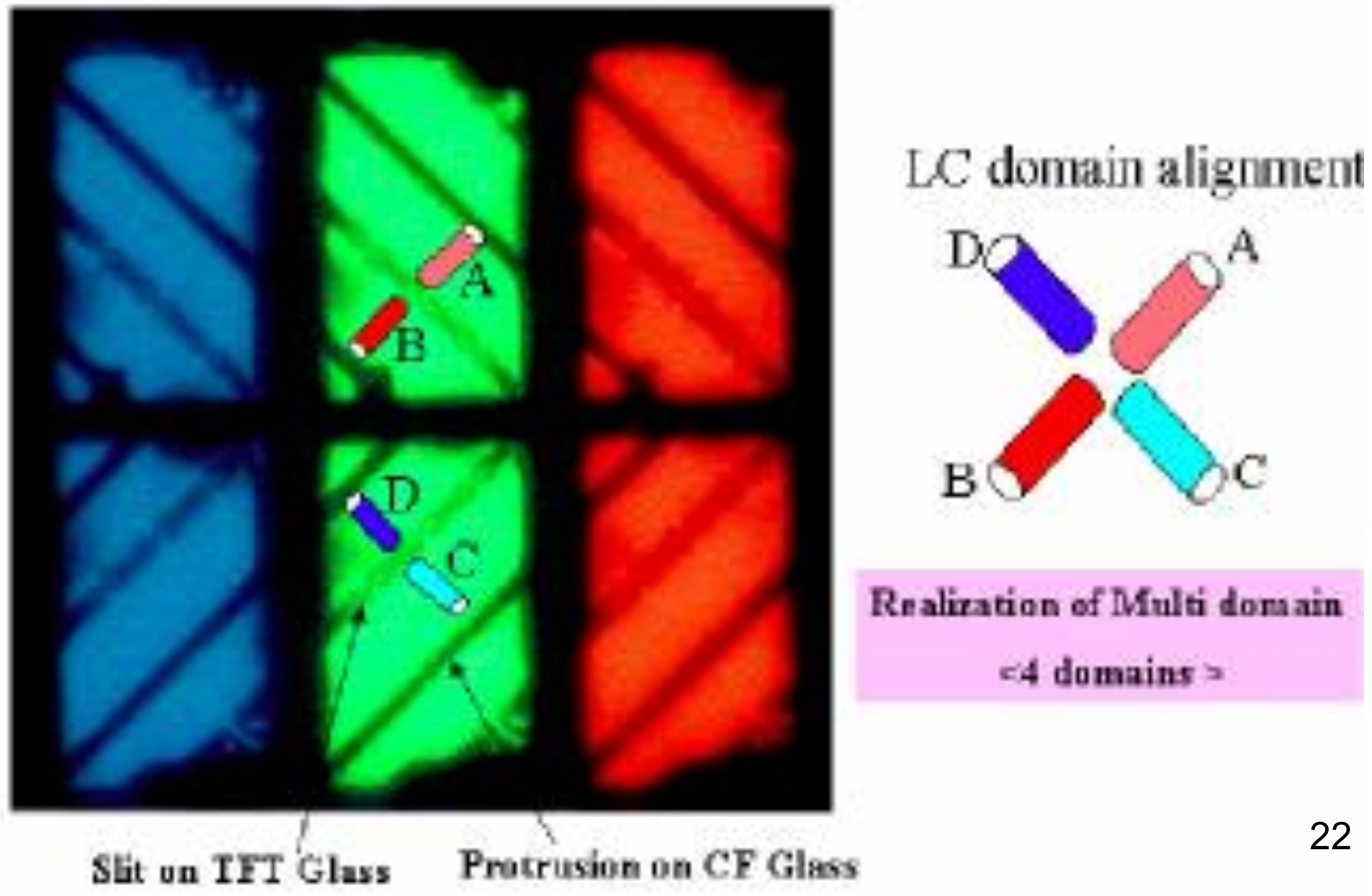




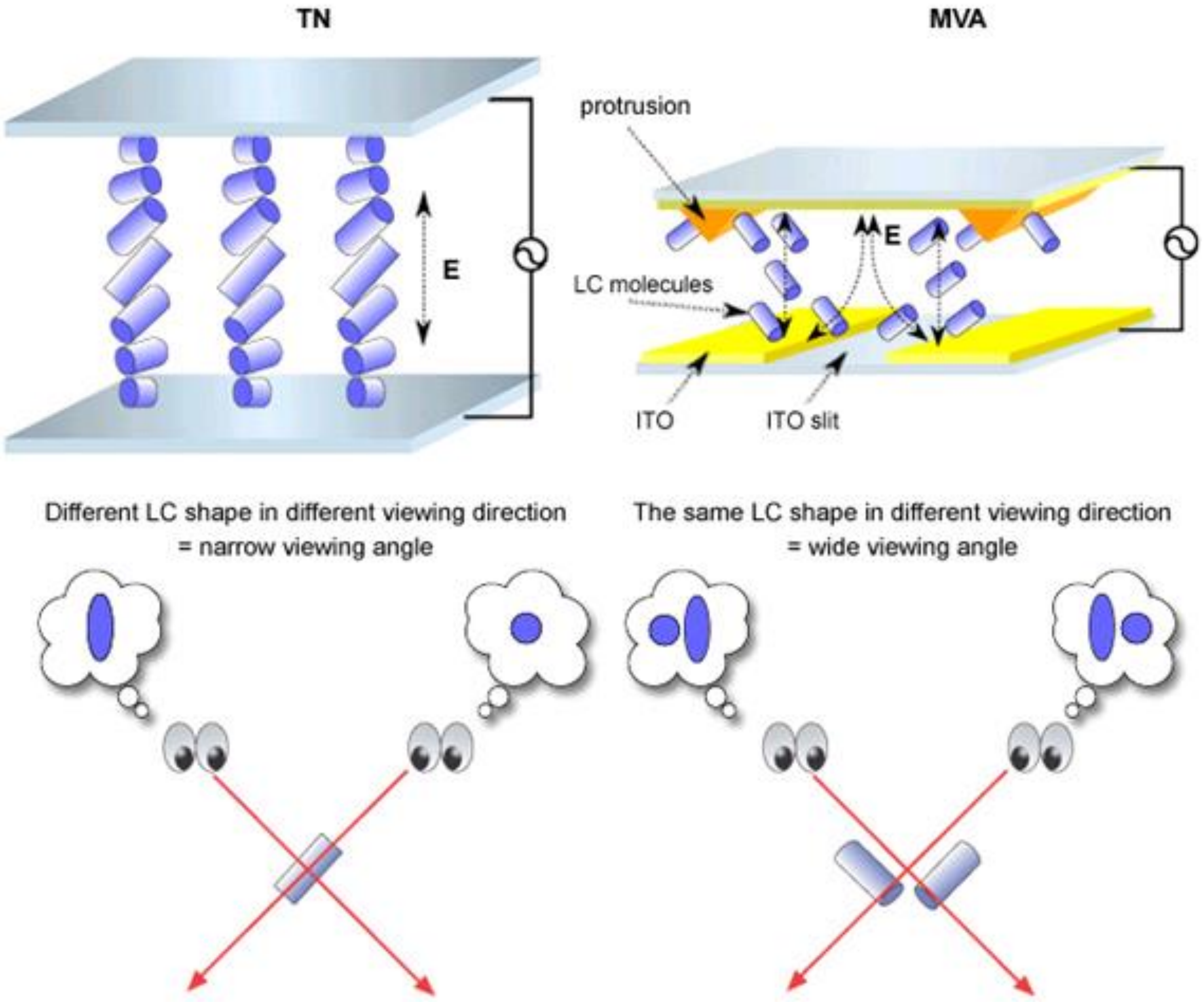
Multiple Vertical Alignment (MVA)

- Simple idea: VA but in several directions simultaneously
- Helps average out angular dependence from different tilt directions
- Gives most uniform contrast as a function of viewing angle
- Viewing angle stability preference depends on application:
  - TV → Horizontal
  - Laptop → Vertical
  - Mobile → Both?





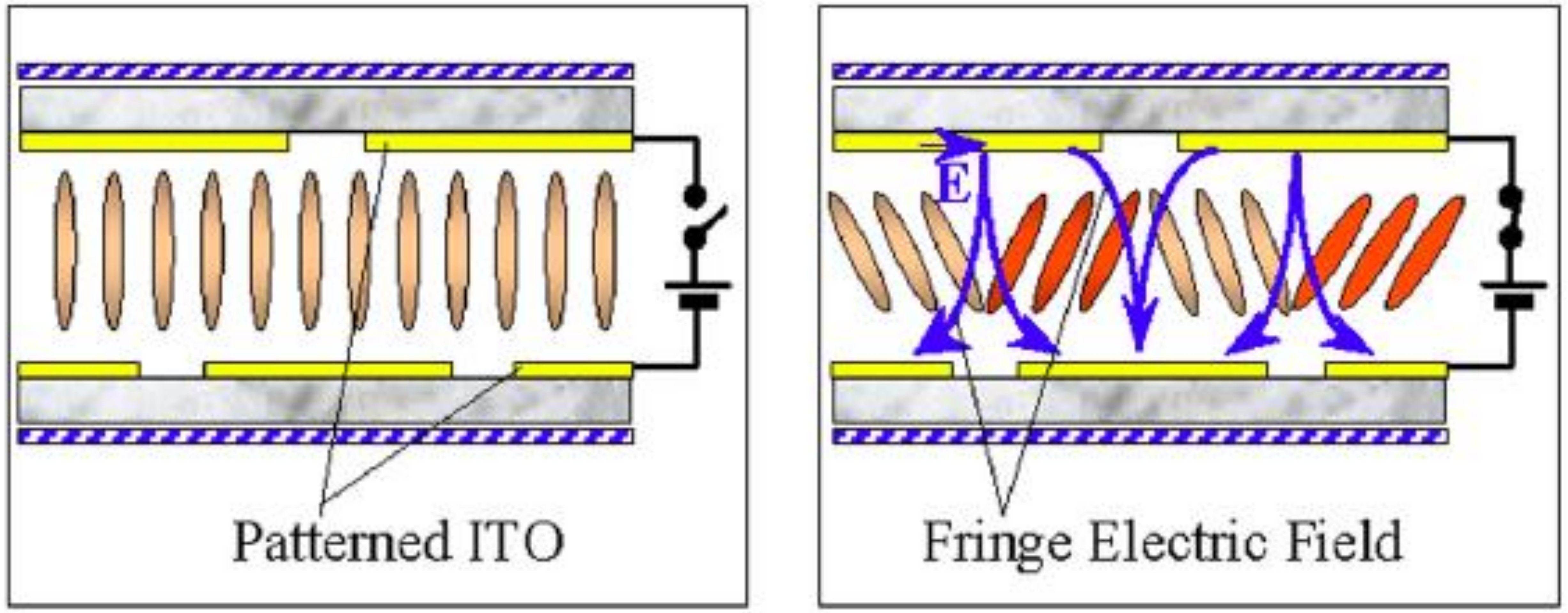
MVA Viewing Angle



Credit: Chee-Mei, Innolux

Patterned Vertical Alignment (PVA)

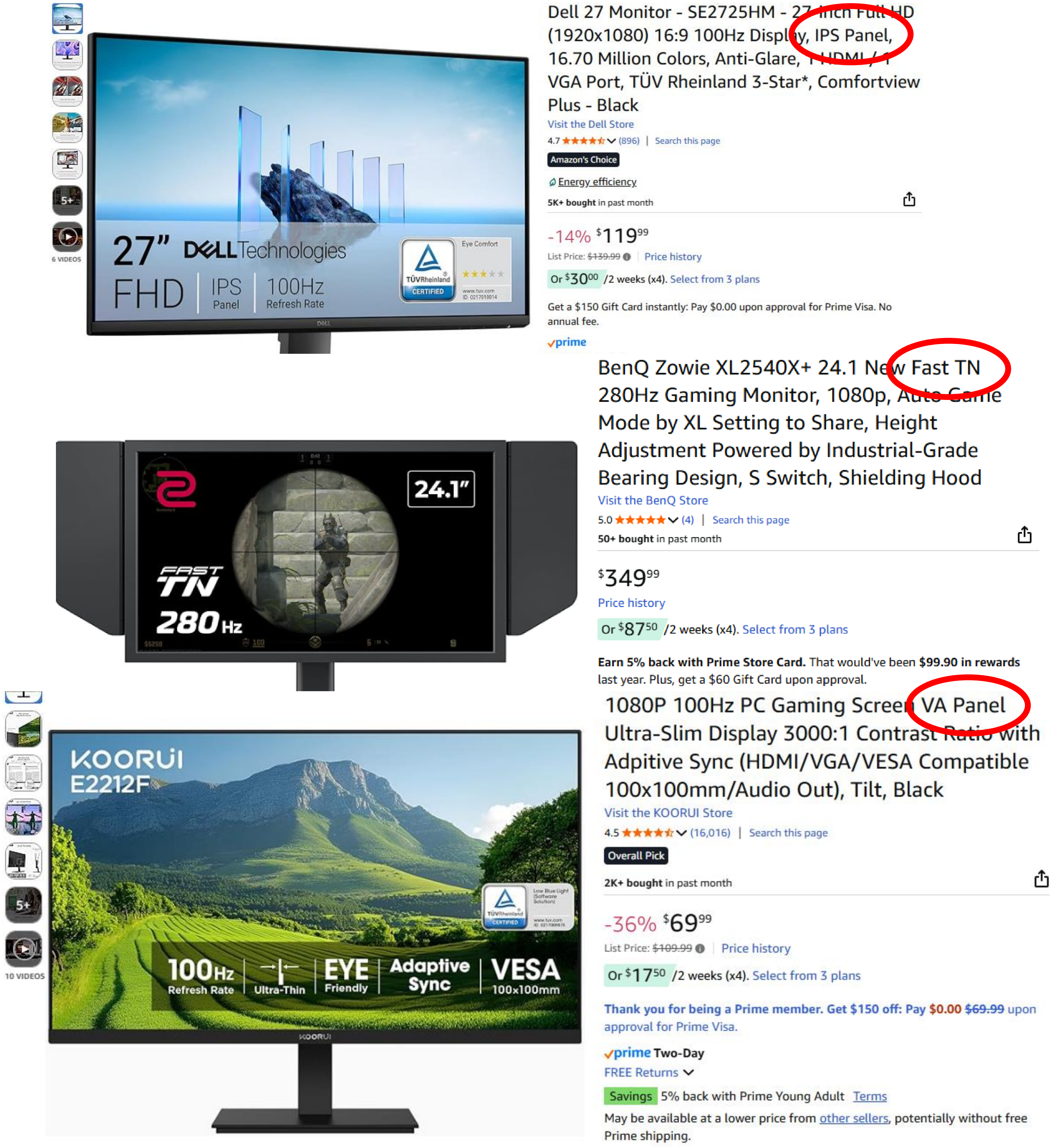
- This was a development that allowed Samsung to make VA a lot cheaper, and with slightly higher performance
- Doesn't use physical protruding pre-tilt layer
- Instead polymerized reactive mesogens (like the waveplates!) as a template
- Makes manufacturing simpler and cheaper
- Easier to make more zones which improves homogeneity



(a) Off state (Black) (b) On state (White)

The Picture Today

- You can buy TN, IPS, and VA LCD displays:
- TN:
  - Fastest response times
- IPS:
  - Best viewing angle
  - Best color
- VA:
  - Deepest blacks
  - Slightly slower than IPS



Source: Amazon

High Dynamic Range

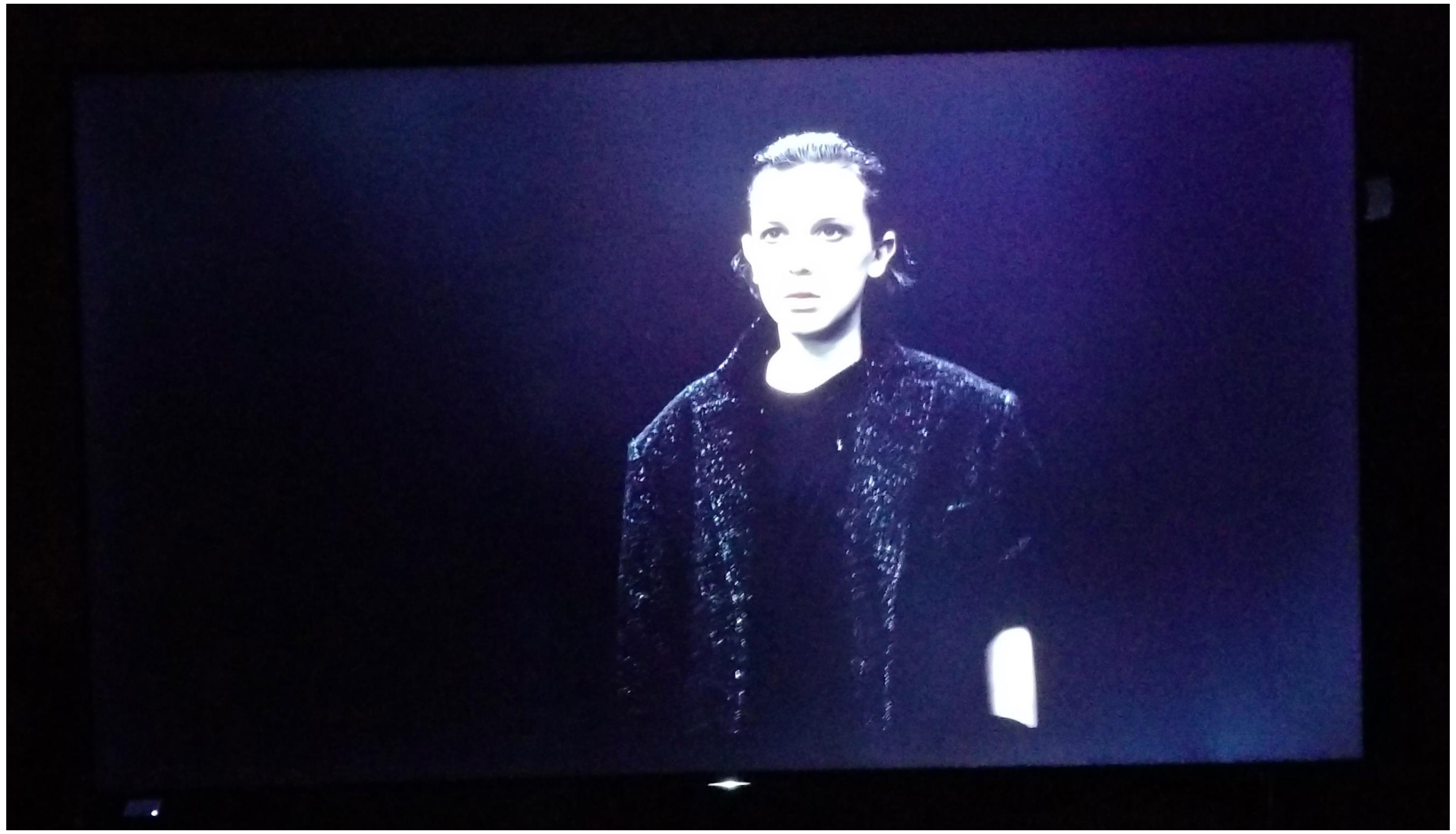
- The contrast for LCDs is ≈1000:1
- HDR1000 standard is 3000:1
- Sounds like a lot, but the eye is capable of many more orders of magnitude
- LCDs have “backlight bleed” → Areas that should pure black are instead dim grays
- This is a pretty extreme example…

Solutions for HDR: Backlight Local Dimming

Instead of having a single backlight → Use an array of LEDs

Solutions for HDR: Backlight Local Dimming

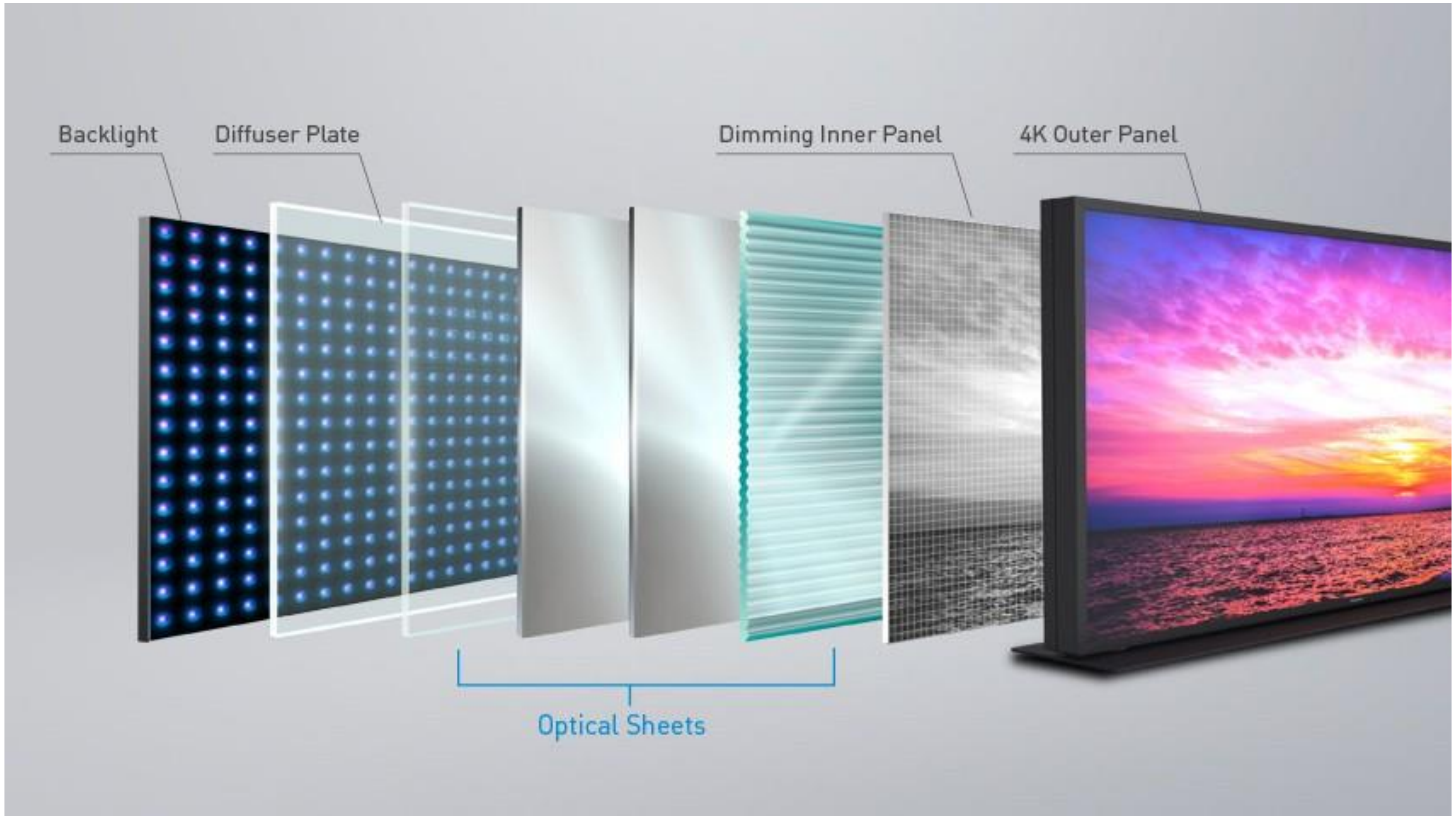
- It's better, but not perfect
- "Blooming" still occurs because you don't have as many backlight elements as pixels
- Aso the algorithm for deciding whether to turn them on isn't perfect
- Jargon for this is "full array local dimming" (FALD) or "miniLED"
- Modern FALD/miniLED displays have 1000-2000 zones for monitors, more for large TVs



Solutions for HDR: Double Layer LCD Local Dimming

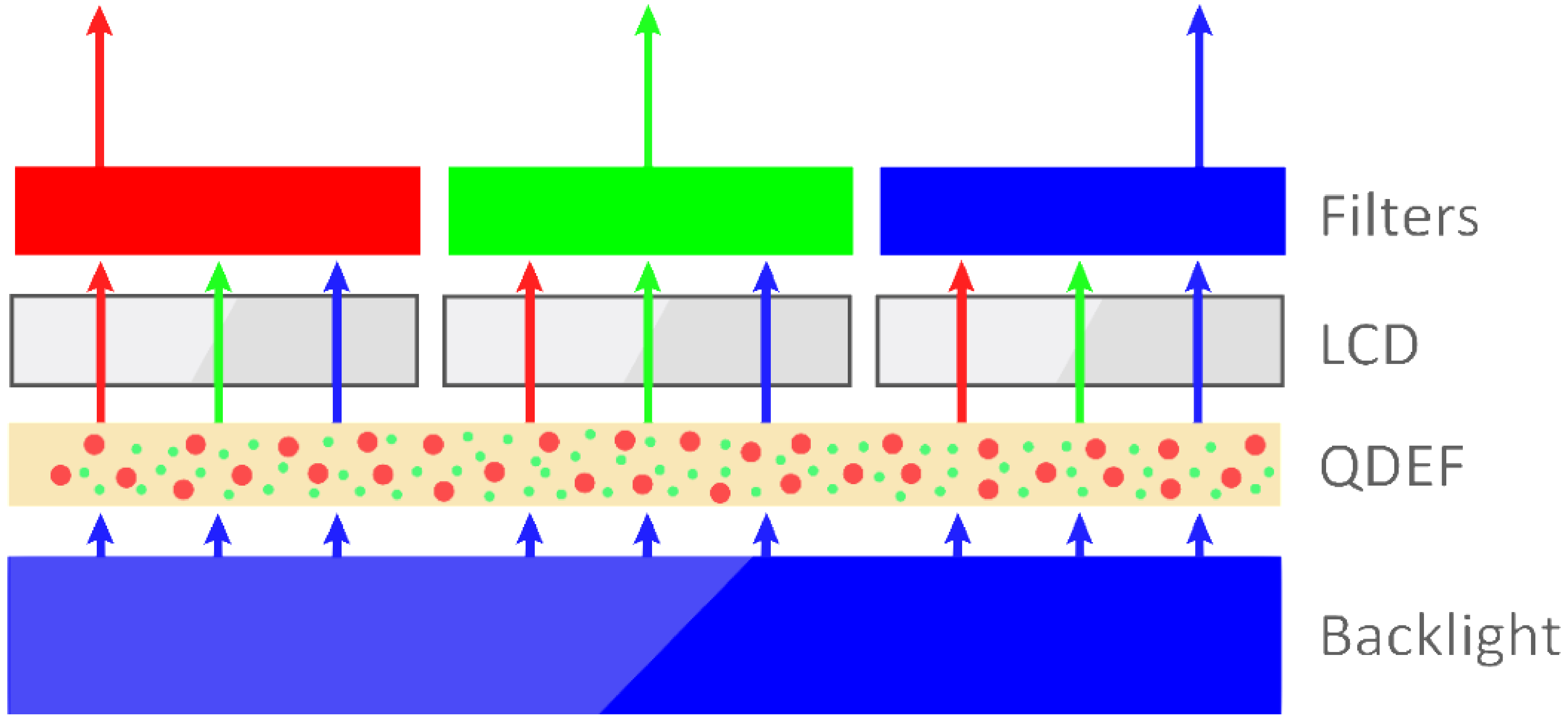
- Essentially stacking two LCDs on top of each other
- Top → Main high-res display
- Bottom → Low-res for local dimming
- Result? Picture looks great!
- Issue? Expensive, heavy, thick, power-hungry…
- No serious development of these anymore…

Panasonic MEGACON



Aside: Quantum Dot LCD

- Instead of white backlight and color filter
- Use blue backlight, down-convert to R/G, then filter
- Benefits:
  - Purer colors → Narrow QD emission spectra
  - Slightly more efficient/bright
- The main brand name for this is “QLED” from Samsung
- It’s still an LCD panel, but with blue LED backlight, and QDs for color conversion



Source: Display Daily

Summary

- LCD TVs/monitors first came onto the scene in the '90s

- Since then, there have been incredible advances in the technology
  - New types of LCs
  - Optical compensation films
  - Backlight patterning strategies
  - QDs for color gamut

- These have improved switching speed, viewing angle, contrast, and resolution

- The result: LCDs dominate because they are good enough, big enough, and cheap enough