Contents of the Lecture

5. Computer Displays

- Liquid Crystal Displays
- Organic LED Displays
- Electronic Paper Displays
- Quantum Dot Displays

Liquid Crystal Displays

- Liquid Crystals
- Twisted Nematic Technology
- Backlighting Types
- Addressing Techniques
- Display Parameters
- Vertical Alignment Technology
- In-Plane Switching Technology

Liquid Crystals (1)

- Liquid crystals: discovered in 1888
  - Changing the state of a material known as cholesteryl benzoate from solid into liquid
- Substances that exhibit anisotropy of properties → variable depending on the direction of measurement
- Equilibrium state – mesomorphic
  - State between solid crystalline and liquid

Liquid Crystals (2)

- Light passing through liquid crystals follows the alignment of the molecules
- Applying an electric or magnetic field changes the molecular alignment of liquid crystals
- Three types of liquid crystals:
  - Thermotropic
  - Lyotropic
  - Metallotropic

Liquid Crystals (3)

- Thermotropic liquid crystals
  - Transition into several phases with temperature changes
- Lyotropic liquid crystals
  - Present phase transitions primarily determined by the concentration of molecules in a solvent
- Metallotropic liquid crystals
  - Composed of organic and inorganic molecules
  - Phase transitions also depend on the organic / inorganic composition ratio

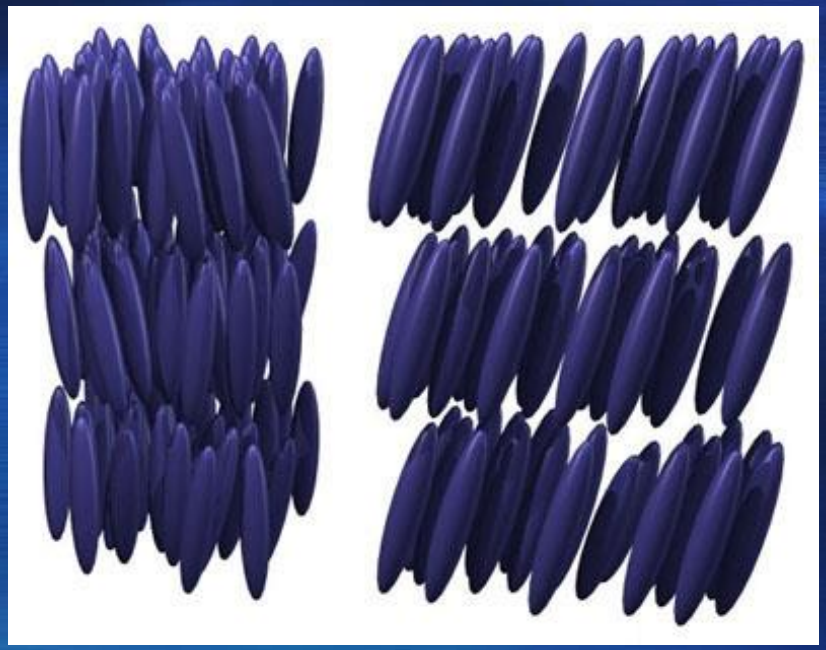
Liquid Crystals (4)

- Phases of thermotropic liquid crystals
  - High temperature: liquid (isotropic) phase
  - Low temperature: solid (crystalline) phase
  - Nematic phase
  - Smectic phase
  - Cholesteric phase
- Types of ordering for the phases:
  - Positional order of molecules
  - Orientation order of molecules

Liquid Crystals (5)

- Nematic phase (N)
  - *Nema* – thread; *nemato* – threadlike (Greek)
  - Threadlike molecules
  - No positional order
  - Approximately parallel orientation order → director
  - Can be easily aligned by an electric field

Liquid Crystals (6)



- Smectic phase (Sm)
  - Molecules maintain the orientation order
  - They align in layers
  - Positional order along one direction
  - SmA (left)
  - SmC (right)
  - Other Sm phases exist

Liquid Crystals (7)

- Cholesteric phase
  - Typical for cholesterol esters → cholesteric
  - Chiral molecules: have no internal plane of symmetry
    - Chiral nematic (N*)
  - Structure similar to a stack of 2D nematic layers
    - The director in each layer is twisted
  - Twisted nematic (TN)

Liquid Crystal Displays

- Liquid Crystals
- Twisted Nematic Technology
- Backlighting Types
- Addressing Techniques
- Display Parameters
- Vertical Alignment Technology
- In-Plane Switching Technology

Twisted Nematic Technology

- Twisted Nematic Technology
  - Principle of Operation
  - Display Structure
  - Super-Twisted Nematic Technology
  - Double Super-Twisted Nematic Technology
  - Film Super-Twisted Nematic Technology

Principle of Operation (1)

- Liquid crystal displays are passive
- Use a light source (backlight) or a mirror (to reflect ambient light)
- The operation is based on the properties of polarized light
  - The light waves are oriented in parallel with a specific direction
  - Can be obtained with a polarizer

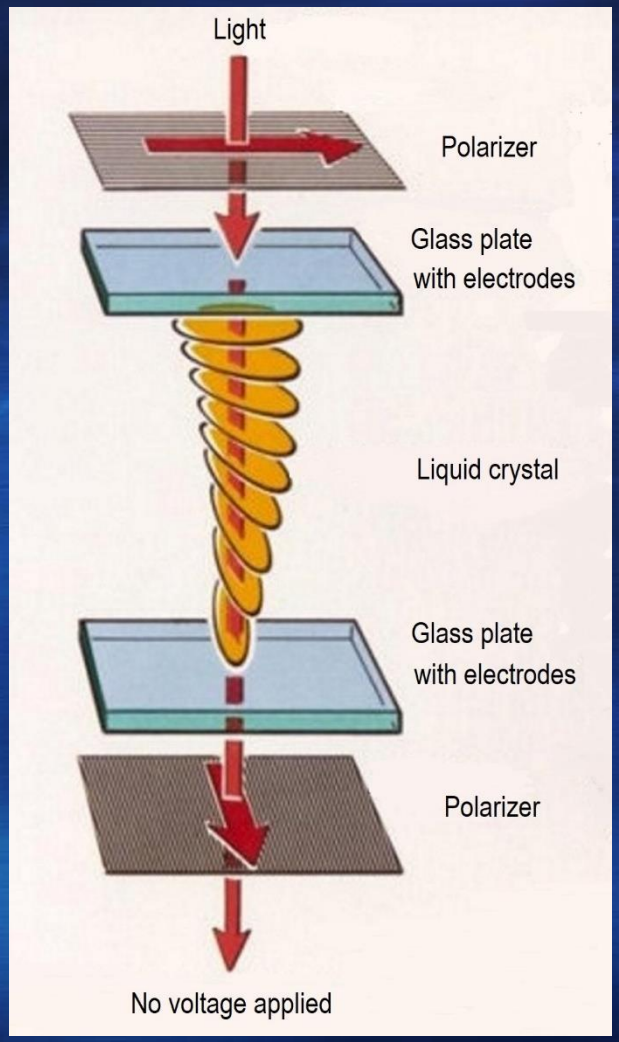
Principle of Operation (2)

- The polarized light passes through a TN liquid crystal layer
  - The light follows the alignment of molecules
  - The polarizing direction is changed by the twisting of molecules

Principle of Operation (3)

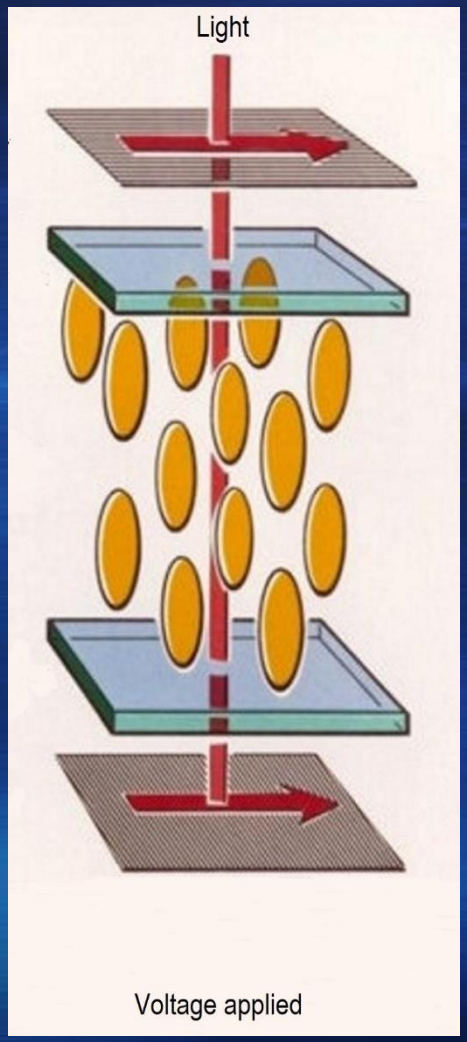
- Single pixel: TN liquid crystals placed between two transparent electrodes
  - The electrodes are provided with alignment layers to control molecule alignment → grooves
  - The grooves on the two electrodes are perpendicular to each other
  - This results in a 90° twist of the longitudinal axes of molecules on the two electrodes

Principle of Operation (4)



- Two polarizers
- Two glass plates
- Two transparent electrodes
- TN liquid crystal layer
- No voltage is applied:
  - The light is polarized by the first polarizer
  - The polarizing direction is twisted with 90°
  - The light will also pass through the second polarizer

Principle of Operation (5)

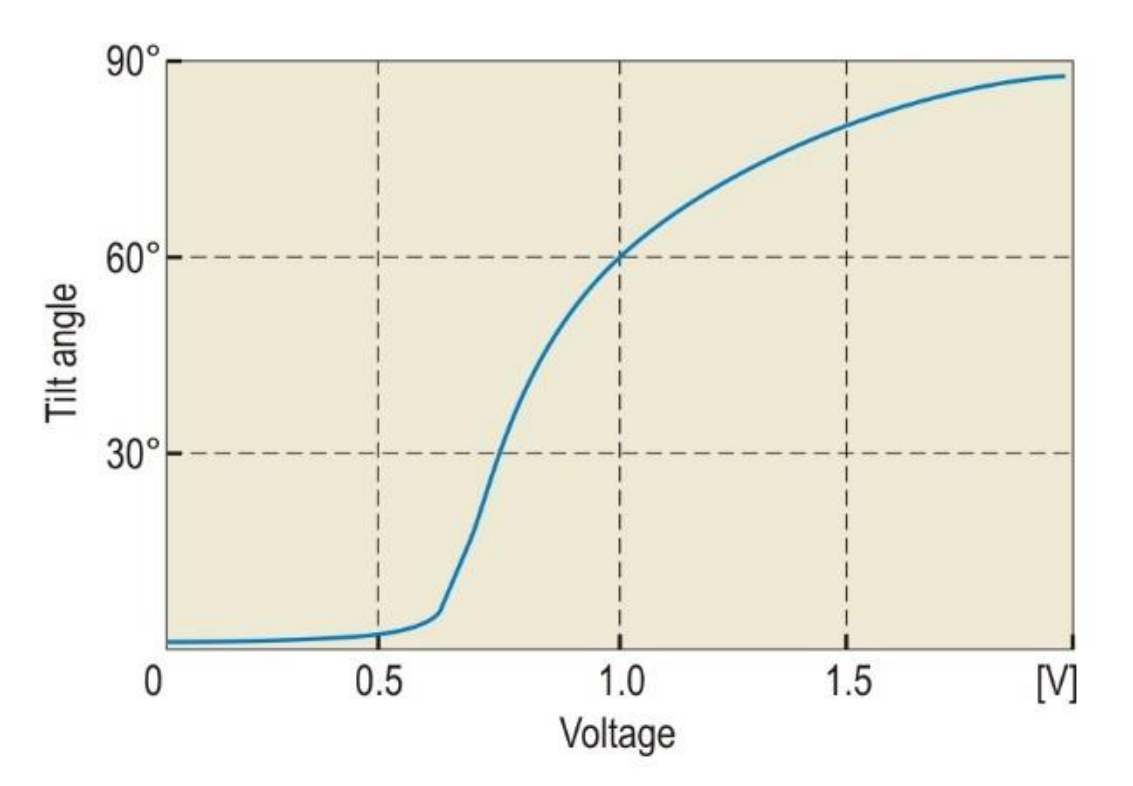


- Voltage is applied:
  - The molecules realign
  - The direction of longitudinal axes tends to align in parallel to the field
  - The light is not twisted ⟶ is blocked by the second polarizer
  - By controlling the voltage, different levels of gray can be obtained

Principle of Operation (6)

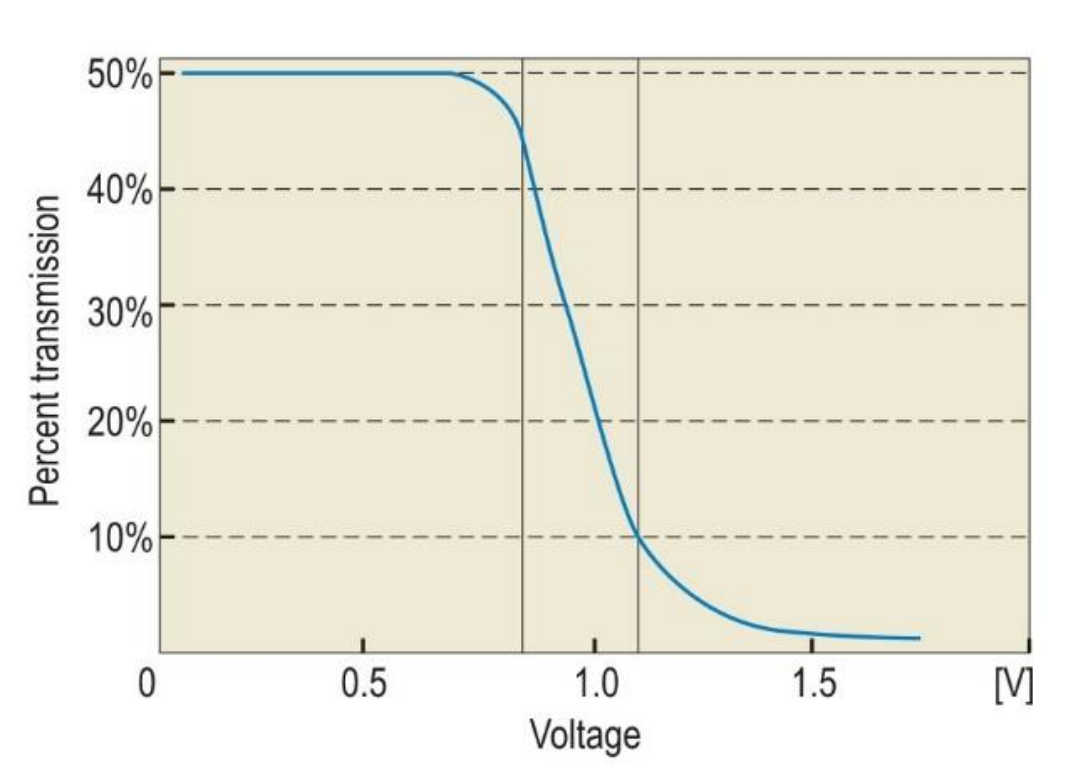
- Displays for which the light is blocked in the areas with no voltage applied
  - The polarizing directions are parallel
  - The optical effect is more dependent on the thickness of display when no voltage is applied
  - The eye is more sensitive to variations of brightness in the dark state → spotted image
  - This variant may also increase power consumption

Principle of Operation (7)



Response of a TN cell to an applied voltage

Principle of Operation (8)



Percent transmission of light for a TN cell

Principle of Operation (9)

- Color displays
  - Intermediate levels of brightness are required
  - Changing the voltage applied to the cells
  - The white backlight contains all the wavelengths
  - The color components are obtained through filtering of the white light
  - Each pixel is composed of three subpixels for the primary R, G, and B colors → additive synthesis

Twisted Nematic Technology

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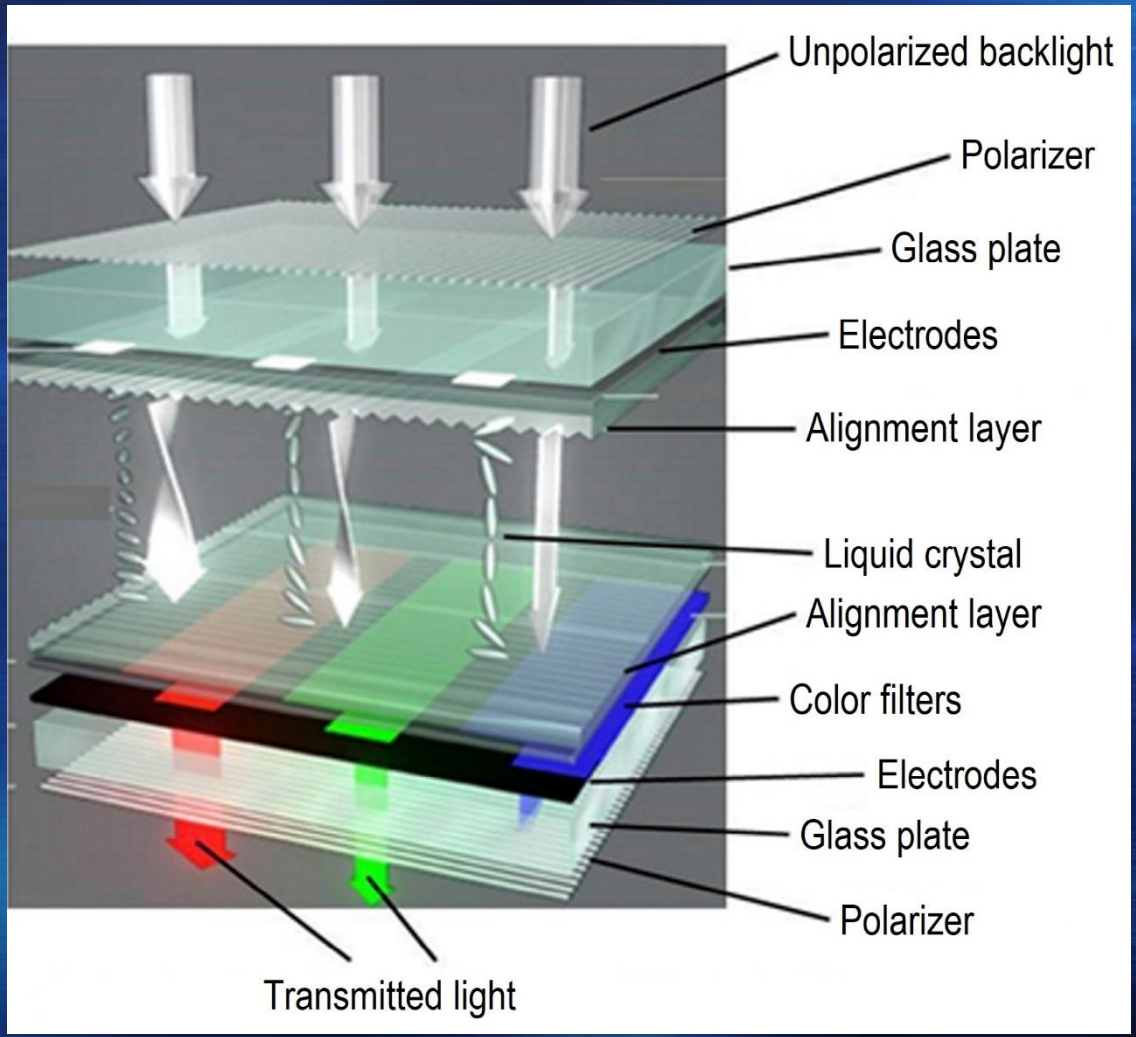
Display Structure



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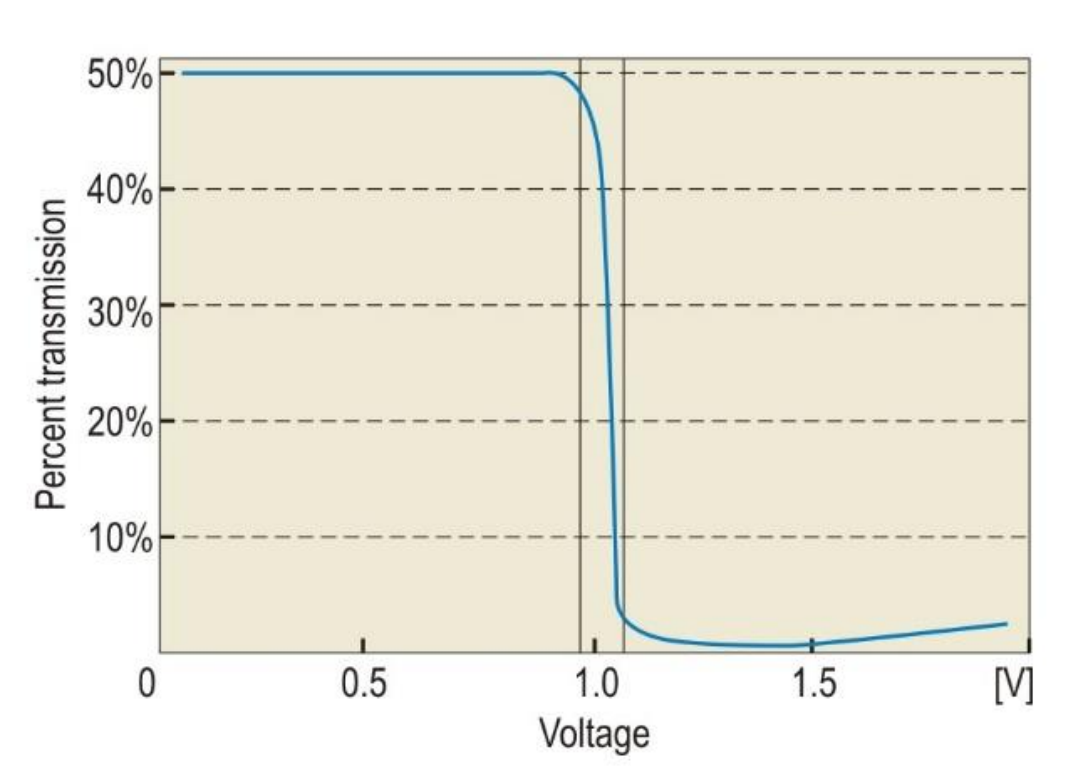
Super-Twisted Nematic Technology (1)

- STN – *Super-Twisted Nematic*
- The difference between the voltages for which a cell is ON/OFF must be very small
- The TN technology is impractical for large sizes with conventional addressing
- STN technology: the direction of the polarized light is rotated with an angle of 180° .. 270°
- The diagram representing the light transmission becomes more abrupt

Super-Twisted Nematic Technology (2)



Percent transmission of light for an STN cell with a twist angle of 270°

Super-Twisted Nematic Technology (3)

- Advantages of STN technology compared to the TN technology:
  - Higher contrast ratio
  - Wider viewing angle
  - Simpler control for the percent transmission of light through the liquid crystal cells
    - Enables to increase the number of rows that can be displayed simultaneously

Super-Twisted Nematic Technology (4)

- Disadvantages of STN technology:
  - Slower response time compared to the TN technology
  - Lower brightness level
  - Higher manufacturing costs
  - Early STN displays presented an undesirable coloration → shifted transmission spectrum
    - In the ON state: yellow
    - In the OFF state: bluish

Twisted Nematic Technology

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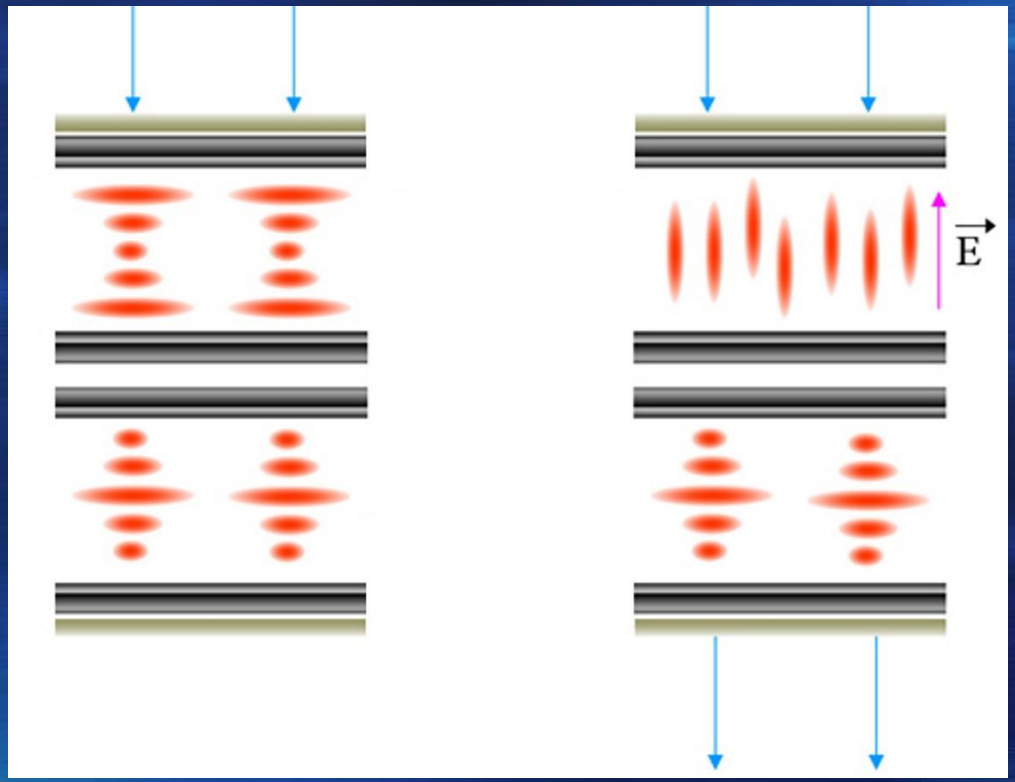
Double Super-Twisted Nematic Technology (1)

- DSTN – *Double Super-Twisted Nematic*
- Solved the coloration problem of the STN technology by adding a second STN layer
  - Without electrodes or polarizers
  - The twisting direction of the polarized light is opposite to that of the first layer
- In the OFF state, the phase shift due to the first layer is compensated by the second layer → black cell

Double Super-Twisted Nematic Technology (2)



DSTN cell in OFF state (left) and ON state (right)

Double Super-Twisted Nematic Technology (3)

- The ON state of the pixel is not affected by the second STN layer → white pixel
- Both layers consist of the same type of liquid crystal → the characteristics are constant
- Disadvantages:
  - More intense backlight is required
  - Higher cost
  - Higher thickness and weight

Twisted Nematic Technology

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Film Super-Twisted Nematic Technology

- FSTN – *Film Super-Twisted Nematic*
- Color compensation is achieved with a thin polymer film instead of a glass layer
- Advantages compared to DSTN technology:
  - Lower cost
  - Lower thickness and weight
  - Lower-power backlight
- Disadvantage:
  - Reduced contrast

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Backlighting Types (1)

- Fluorescent lamp backlighting
  - CCFL – *Cold Cathode Fluorescent Lamp*
  - Placed at the edges of the display
  - For uniform distribution of light: light guide plate (LGP) and diffuser panel
  - Disadvantage: low energy efficiency
  - For portable devices, the voltage needs to be converted to a high voltage
  - It is not possible to build thin displays

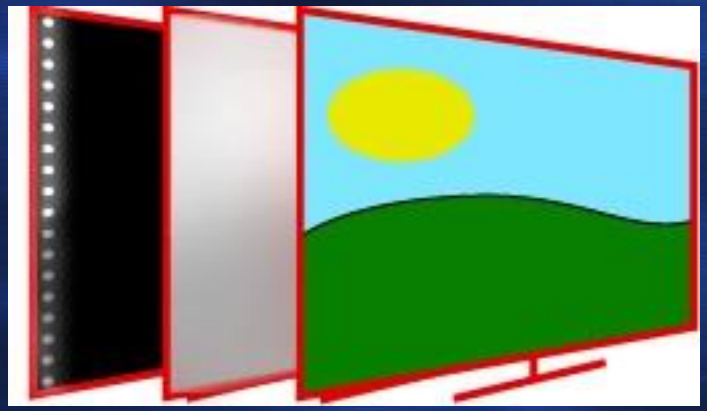
Backlighting Types (2)

- LED backlighting
  - Most used type of backlighting
  - Displays and TV sets with LED backlighting (LED displays, LED TVs) use a liquid crystal display technology → improper names
  - Advantages compared to CCFL backlighting:
    - Reduced power consumption (35..40%)
    - LED lifetime is longer
    - Very thin displays can be built (< 1 cm)
    - Higher contrast and brightness

Backlighting Types (3)

- Disadvantages of LED backlighting:
  - More difficult to maintain the uniformity of brightness in the long term → brighter or darker areas
  - The color range (gamut) is slightly narrower compared to that of CCFL lit displays
- Edge-Lit White LED (EL-WLED) backlighting
  - Rows of white LEDs placed at the edges of the display
  - Variants with the LEDs placed on four sides, two sides, or one side

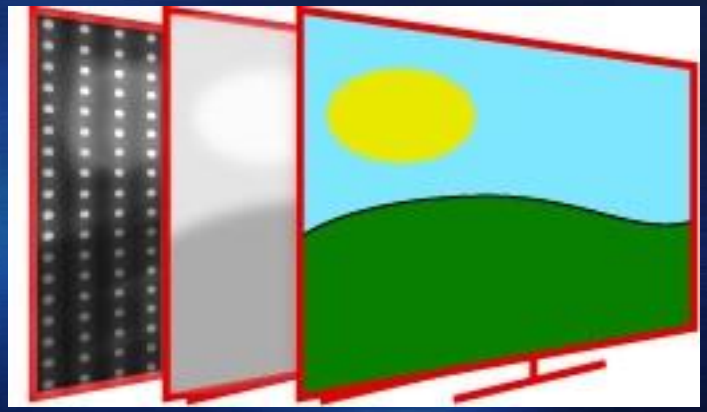
Backlighting Types (4)



- "Local Dimming" feature: changing the brightness separately in different regions
  - Dividing the rows of LEDs into zones and controlling independently the brightness
  - Improves the apparent contrast ratio

Backlighting Types (5)

- White LED array backlighting
  - Array of white LEDs uniformly distributed behind the display panel
  - "Full-Array Local Dimming" (FALD) feature: setting the backlight intensity differently in different zones



Backlighting Types (6)

- The FALD feature enables better control of the brightness than “local dimming”
  - A much higher dynamic contrast ratio can be achieved
  - Mostly used in TV sets
  - Few computer displays with the FALD feature: 384 zones (27-inch), 512 zones (35-inch)
- Mini LED array backlighting
  - Size of a Mini LED: 100 .. 200 µm
  - Enables to increase the number of zones used by the FALD feature

Backlighting Types (7)

- First displays with Mini LED backlighting:
  ASUS ProArt PA32UCX (32-inch, >1000 zones),
  ASUS ProArt PA27UCX (27-inch, 576 zones)

ASUS ProArt PA32UCX display (© ASUSTeK Computer Inc.)

Backlighting Types (8)

- RGB LED array backlighting
  - Similar to white LED array backlighting, but uses an array of RGB LED triads
  - An extended color range can be achieved
  - Pure and saturated colors
  - Used in professional-grade displays for graphics editing, photography, video/film post-production, visual effects, animation
  - High cost

Backlighting Types (9)

- Example of professional-grade display: HP DreamColor Z31x Studio Display
  - Built-in colorimeter: automatically performs the color calibration process

© HP Development Company, L.P.

Summary (1)

- Liquid crystals have properties of the liquid matter and of the crystalline solid matter
- Types of liquid crystals: thermotropic, lyotropic, metallotropic
- Thermotropic liquid crystals present several phases depending on temperature
- Twisted Nematic (TN) has been the first technology used for liquid crystal displays
  - It is based on the properties of polarized light, which follows the alignment of molecules

Summary (2)

- Improvements of the TN technology: Super TN (STN), Double STN (DSTN), Film STN (FSTN)
- Backlighting types
  - Fluorescent lamp
  - LED
  - Edge-Lit White LED
  - White LED array
  - Mini LED array
  - RGB LED array

Concepts, Knowledge (1)

- Types of liquid crystals
- Phases of thermotropic liquid crystals
- Nematic phase
- Smectic phase
- Cholesteric phase
- Principle of operation of Twisted Nematic (TN) liquid crystal displays
- Super TN (STN) technology

Concepts, Knowledge (2)

- Double STN (DSTN) technology
- Film STN (FSTN) technology
- Fluorescent lamp backlighting
- Advantages/disadvantages of LED backlighting
- Edge-lit white LED backlighting
- White LED array backlighting
- RGB LED array backlighting