Chapter 5: Computer displays

1. **Explain the nematic phase of thermotropic liquid crystals**

A: The nematic (N) phase is one of the most common liquid crystal phases. The word nematic originates from the Greek "nema", which means "thread" (the Greek 'nemato" means "threadlike"). Nematic is the simplest and least ordered phase. Organic materials in this phase have threadlike molecules with no positional order, but the molecules have an approximately parallel orientation order, with their long axes roughly parallel. The vector of this preferential orientation is called the director. The molecules are free to flow (they have fluidity like that of liquids), but still maintain their directional order. Nematic liquid crystals can be aligned easily by an electric or magnetic field. They have the optical properties of uniaxial crystals, which makes them useful in liquid crystal displays (LCDs).

2. **Explain the cholesteric phase of thermotropic liquid crystals**

A: The cholesteric phase is typical for cholesterol esters, which are cholesterol derivatives. Only chiral liquid crystal molecules, which are those that are not identical to their mirror image, can exhibit this phase. Liquid crystal phases of chiral molecules are labeled with an asterisk. The nematic phase of a chiral liquid crystal is also called chiral nematic and is abbreviated as N*. If a nematic liquid crystal is chiral, then adjacent mesogens will have a preferential twist with respect to one another because they do not line up when combined, which leads to the twisting of the internal order. The structure is similar to a stack of two-dimensional nematic layers. The nematic director in each layer is twisted with respect to adjacent layers, so that the directors form a continuous helical pattern. After a certain number of layers, the molecules rotate a full turn of 360 degrees. Due to this arrangement, the chiral nematic phase is also called twisted nematic (TN).

3. **Explain the operation of a TN liquid crystal display cell**

A: Unlike cathode ray tube displays and plasma displays, which are active, LCDs are passive because liquid crystals do not emit light directly. Therefore, they use a light source as backlight, or a mirror that reflects ambient light. The operation of TN LCDs is based on the properties of polarized light. The light waves of a polarized light are oriented in parallel to a specific direction, which is the direction of polarization. This is contrary to natural light, where the waves are oriented in random directions. Polarized light can be Obtained with a polarizing filter, which blocks light waves that are not parallel to a direction specific to the filter. When polarized light passes through a TN liquid crystal layer, the light follows the alignment of liquid crystal molecules. Since the molecules are twisted with respect to neighboring molecules, the polarizing direction is changed by the twisting of molecules. Therefore, the light is repolarized by the twisting of liquid crystal molecules.

4. **Explain why the STN technology is more advantageous than the TN technology for large displays with conventional addressing**

- Increased contrast ratio(10:1)
- Increased viewing angle(up to 75')
- Simpler control which enables to increase the number of rows that can be displayed simultaneously thus increasing the size of the displays

5. **Explain the DSTN and FSTN improved TN technologies**

A: Double Super-Twisted Nematic(DSTN) technology solves the coloration problem of STN. This technology adds a second STN layer without electrodes or polarizers, but with the twisting direction of the polarized light opposite to that of the first layer.

Advantages:

- correct colors can be achieved

- contrast ratio nearly twice as high as the STN technology

Disadvantages:

- a more intense backlight is required to compensate for transmission losses due to the second STN layer
- cost

Film Super-Twisted Nematic(FSTN) technology achieves the color compensation with a thin polymer film, which replaces the second STN glass layer. The polymer has double refraction to remove the color shift and is placed either under or over the top polarizer. Some displays use two films, one at the rear that acts as a collimator, and one at the front that acts as a dispersion film to broaden the viewing angle.

Advantages:

- lower cost
- reduced thickness and weight
- lower-power backlight

Disadvantages:

- reduced contrast

6. **Difference between Direct addressing and multiplexed addressing**

Direct addressing	**Multiplexed addressing**
• can only be used for displays with small number of elements that have to be activated • each element(segment or pixel) can be addressed or driven separately because it has its own driver circuit • a voltage should be applied to each display element to change orientation of liquid crystal molecules • common application is the seven-segment display	• can be used to address displays with large number of pixels which need to be activated • when pixels are arranged in a matrix they can be addressed by a matrix of rows and columns instead of individual addressing • each pixel sits at the intersection of a row electrode and a column electrode • a pixel is only activated when a voltage is applied to both electrodes • the voltage range needs to be much smaller than with direct addressing in order to change activating voltage for a large amount of pixels • reduces complexity(1000x1000 = 2000 drivers instead of 1000000) • contrast ratio is also reduced

7. **Disadvantages of passive-matrix LCDs**

- Crosstalk(“ghosting”) which represents the interference between neighboring pixels. Crosstalk occurs because the voltage applied to a pixel also affects adjacent pixels, causing the appearance of shadows for bright objects and reducing the contrast ratio
- Related to STN liquid crystals, as TN liquid crystals cannot be used in PM displays with multiplexed addressing, viewing angles are limited

- Response time is slow which causes the image to be maintained for a certain time on the screen after the image is displayed

8. **Semiconductor materials that can be used in the thin-film transistors(TFTs) of active-matrix LCDs**

While for early TFTs compounds such as cadmium sulfide (CdS) and cadmium selenide (CdSe) were used as semiconductors, afterwards silicon was commonly used as active semiconductor material.
There are three different types of silicon that can be used, **crystalline silicon**, **amorphous silicon**, and **polysilicon.**
In addition to silicon used as semiconductor, several types semiconducting metal oxides can also be used as active semiconductor materials. Some of these materials, such as **zinc oxide** (ZnO) and related compounds like aluminum-doped zinc oxide (AZO), indium zinc oxide (IZO), and indium **gallium zinc oxide** (IGZO), are transparent and present advantageous features, such as high optical transmittance in the visible range, high electron mobility, and low manufacturing cost. These materials, which have been intensively researched in the last 15 years or so, might replace Si and poly-Si in TFTs of AM displays. They are also suitable for transparent and flexible substrates, enabling the development of the next generation of thin display panels.

9. **Types of defective pixels that may be present in active-matrix LCDs**

- **Lit pixel("hot pixel")** is permanently turned on and appears as a white dot on black backgrounds
- **Black pixel("dead pixel")** is permanently turned off and appears as a black dot on ligh backgrounds
- **Stuck pixel** is the result of one or two of its subpixels being permanently turned on or off which makes the pixel to appear as a colored dot that is either red, green, blue or one of the secondary colors

10. **Variants of LED backlight systems used for LCDs**

CCFL (Cold Cathode Fluorescent Lamp) backlighting uses fluorescent lamps that are usually placed at two opposite edges of the display. For uniform distribution of the light, a light guide plate (LGP) and a diffuser panel are placed in front of the fluorescent lamps. This type of backlighting system has been widely used before LED backlighting became widespread. Its disadvantage is that the fluorescent lamps are less energy efficient. In addition, for LCDs of portable devices the voltage used by these devices must be converted to the high voltage needed for the fluorescent lamps with an inverter. The thickness of this inverter does not allow to build thin displays.
LED backlighting: is currently the most used type of backlighting system. Although originally it was quite expensive, the improved manufacturing processes and reduced production costs have allowed LED backlighting to be used even in the least expensive LCDs. Computer displays and TV sets with this type of backlighting(LED displays and LED TVs) use an active-matrix LCD technology. For this reason, LED display and LED TV are improper names, since the image is generated based on the properties of liquid crystals, and therefore the image quality is primarily determined by the LCD technology used, regardless of the backlighting type.

11. **Advantages of LED backlight over CCFL backlight**

- Reduced power consumption(35-40%)
- LED lifeline is longer
- Higher contrast and brightness
- Very thin displays can be built with a thickness less than 1cm

12. **Principle of Response Time Compensation(RTC) technique**

RTC(or "overdrive") This is a technique for improving response time for all transitions, but especially for grey-to-grey (G2G) transitions. RTC is based on applying an over-voltage to the liquid crystal molecules to stimulate them into their orientation faster. The over-voltage forces the molecules into a grey-to-black transition first, and then into a transition to the required grey level. This technique does not significantly improve black-to-white transitions, for which the maximum voltage is applied anyway, but G2G transitions are significantly accelerated. This is an important advantage since most of the transitions are G2G transitions, and without the RTC technique they are the slowest transitions. Displays using this technique have response times quoted for G2G transitions. The reason is that the ISO black-to-black(B2B) transitions are no longer the fastest, and manufacturers prefer to quote the fastest response time

13. **Difference between static contrast and dynamic contrast ratio**

Static contrast ratio	Dynamic contrast ratio
• **Cannot provide a deep black color, the black will look dark-grey in a dimly lit environment** • **Displays have higher static contrast ratio**	• **Adjusting the intensity of the backlight** • **Reduce the intensity in dark scenes** • **The luminosity of white/black color measured at maximum/minimum backlight intensity**

14. **Spatial dithering technique for improving the color depth**

A new color is created by several neighboring pixels of slightly different colors. The eye will combine the colors of these close-by pixels and therefore a single color tone representing the average of these colors will be perceived which otherwise could not have been reproduced Potential problem is that various patterns might be visible on the screen if the colors of close-by pixels are not carefully assigned

15. **Frame Rate Control(FRC) technique used for improving color depth**

The Frame Rate Control (FRC) technique represents a temporal dithering rather than a spatial dithering. With this technique, the color of a pixel or group of pixels is changed slightly during successive frames. For instance, if a pixel is displayed alternately with two slightly different colors with the frequency of the refresh rate, as the result of the similarity of these colors and the inertia of human eye, the pixel will be perceived in a third, in-between color. When four frames are combined, the color depth may increase to 16.2 million, which is close to the 16.7 million colors that can be reproduced with a 24-bit color representation. However, the quality of color reproduction may be influenced by effects such as slanting stripes appearing on the screen, or flicker that may be perceived for some specific images, particularly in darker shades. The quality of color reproduction is determined by the quality of the FRC algorithm, but generally it is not the same as with true 24-bit color. This quality may also depend on the brightness and contrast settings, so that the image may be at certain settings only.

16. **Concepts of luminance, chromaticity, hue and saturation**

- Luminance is the measure of luminous intensity per unit area and is expressed in cd/m^2 or equivalent called nit. It describes the amount of light that passes through or is emitted from a particular area
- **chromaticity** specifies the quality of a color regardless of its luminance. **chromaticity** can be defined using hue and saturation.
- Hue is related to the wavelength of light in the visible spectrum for spectral colors; a spectral color is composed of a single wavelength. Hue can be described with the names of the colors, and it is the attribute that most clearly differentiates one color from another.

- Saturation is the ratio of the dominant wave-length to other wavelengths in the color; it is also called color purity. The purest(fully saturated) color is achieved by using a single wavelength with no mixture of white color. Unsaturated colors constitute the greyscale.

17. **Techniques that can be used for enhancing viewing angles**

- Reduced cell depth: in a LCD panel the depth of a cell(sub-pixel) is one of the factors that determines the quantity of light escaping through the cell. Light passes from the backlight through each cell and then escapes throught the top of the cell. The shallower the cell the more light can escape at greater angles. The reduced cell depth can be combined with an increased aperture ratio of each cell, which will allow more light to pass through from the backlight increasing the brightness of the panel without increasing the power consumption. This is achieved by reducing the size of the thin film transistor and the width of the electrodes for each cell

18. **Vertical Alignment(VA) LCD technology**

The technology uses a different type of liquid crystals with the molecules naturally aligned perpendicular to the glass substrates. The polarized light passes through the cell undisturbed by the liquid crystal molecules and is blocked by the front polarized creating a black cell. The obstruction of light is almost complete and therefore a high quality black color is achieved. When a voltage is applied between the two electrodes, the liquid crystal molecules tilt with up to 90' and allow the light to pass through depending on the amount of tilt, creating a grey cell. When the maximum voltage is applied, the molecules shift to a horizontal position, creating a white cell. The molecules are tilted uniformly, but because of the uniform alignment of liquid crystal molecules the brightness of a cell changes with the viewing angle. When the cell is viewed from the front, only part of the light that enters the cell is visible. Therefore, when looking at the screen strictly perpendicularly, some color hues (especially dark hues) are not visible. When the cell is viewed in the direction of the tilt, it appears bright, and when the cell viewed in the direction normal to the tilt, it appears dark. The VA technology enables to achieve faster response times compared to the TN technology', because the liquid crystal molecules are not twisted, and they are simply switched between the vertical and horizontal alignments. Compared to the TN technology, the VA technology enables to achieve a higher-quality black color, higher contrast ratio, and wider viewing angles. However, the image quality depends on the viewing direction (either parallel or normal to the molecules' tilt). Viewing angles are still limited for intermediate alignments between the vertical and horizontal positions. The brightness is dependent on the viewing angle, and color shifting occurs with increased viewing angles.

19. **Explain how the Multi-domain Vertical Alignment(MVA) and improved MVA technologies reduce the brightness dependence on the viewing angle**

Several variants of the original VA technology have been developed to improve it. The Multi-domain Vertical Alignment (MVA) technology, also developed by Fujitsu Ltd., reduces the brightness dependence on the viewing angle. With this technology, each display cell is divided into several regions or domains, and in each domain the liquid crystal molecules are aligned differently than in the adjacent domains. When there are two domains, the liquid crystal molecules on the left and right sides of a cell tilt in opposite directions. By combining areas of molecules oriented in one direction with areas of molecules oriented in the opposite direction, a uniform brightness of the cells can be achieved over a wide range of viewing angles if the size of the areas is very small.

20. **-**

21. **Explain the principle of Patterned Vertical Alignment(PVA) and Super Patterned Vertical Alignment(SPVA) LCD technologies**

The Patterned Vertical Alignment (PVA) technology has been developed by Samsung Electronics in the late 1990s as an alternative to the MVA technology. It offers similar features as the MVA technology, but with some enhancements. The liquid crystals in a PVA display panel are aligned like those in an MVA display panel' in multiple domains with different orientations, which helps to maintain a uniform brightness and color reproduction over a wide range of viewing angles. With the PVA technology, the protrusions on both substrates are replaced with electrodes arranged in a chevron pattern. By replacing all the protrusions, the light leakage is significantly reduced.

22. **Explain the principle of In-plane Switching(IPS) LCD technology. Explain the operation of an IPS cell**

The In-Plane Switching (IPS) technology has been originally developed in 1996 by Hitachi Ltd. In developing this technology, the aim was to overcome the narrow viewing angles that were characteristic of early TN technology. In a conventional TFT TN display, the electrodes of a cell are mounted on separate glass substrates, one above the other. Only the pixel electrode, the one that is positioned at the rear of the display, is controlled by a TFT. In an IPS display, both electrodes of a cell, pixel electrode and common electrode, are mounted on the same glass substrate, in parallel with each other, and therefore they are in the same plane.

Cell functioning:

In the OFF state of a cell, when no voltage is applied between its electrodes, the liquid crystal molecules are aligned in parallel to the glass substrates, just like in a conventional display. The molecules are also parallel to the electrode pair of the cell. However, none of the molecules is anchored to the glass substrate on the back, unlike the molecules at the end of molecule chains in TN displays. The liquid crystal molecules are uniformly aligned throughout the cell and they do not change the light polarization. The second polarizing filter is placed perpendicularly to the front polarizing filter, so that it blocks the light, and the cell appears black. In the ON state of the cell, when a voltage is applied between its electrodes, the liquid crystal molecules can rotate freely up to 90' to align with the electric field, but they remain parallel to the glass substrates. The light polarization is changed, and therefore the light is not entirely blocked by the second polarizing filter. At maximum intensity of the electric field, the cell appears white.

23. **Present the advantages of In-Plane Switching LCD technology**

- Much wider viewing angles(170'). There is no variation in the orientation of the liquid crystal molecules which always remain in the plane of the substrates
- High color reproduction(color reproduction is not affected when touched)
- If a TFT transitior is defective the corresponding sub-pixel remains black which might be less annoying than a bright pixel in a TN panel

24. **Present the advantages of Horizontal In-Plane Switching(H-IPS) LCD technology**

- Aperture ratio of the cell is increased which improves the brightness
- Improved contrast ratio(comparing with SIPS)

25. **Present the advantages of Super In-Plane Switching(S-IPS) LCD technology**

- Improved response time and low contrast ratio
- Improved viewing angles(178')
-

26. **Explain the principle of Advanced High-Performance In-Plane Switching(AH-IPS) LCD technology**

- Increased resolution and pixel density

- Increased aperture(which allows for improved light transmission and reduced power consumption compared to original IPS)

27. ~~**Explain the principle of plasma display panels**~~
28. ~~**Explain the operation of a field emission display**~~
29. **Explain the difference between fluorescent OLEDs and photosphoresent OLEDs**

Fluorescent OLED	**Photophosphorescent OLED**
• **Only singlet states contribute to light emissions. Since only 25% of excitons are in singlet state the efficiency of OLEDs(called internal quantum efficiency) is limited to 25** • **Only singlet excitons decay through fluorescence since there is no spin-orbit coupling to facilitate intersystem crossing from the triplet state to the singlet ground state**	• **The introduction of heavy-metal atoms into the emitting layer increases the spin-orbit coupling. This coupling reduces the lifetime of the triplet state to the order of microseconds and it makes possible a transition from the triplet state to the singlet ground state followed by light emission which would normally be forbidden** • **The spin-orbit coupling facilitates intersystem crossing(ISC) between the excitet singlet state and the excited state**

30. ~~**Explain the operation of Thermally Activated Delayed Fluorescence (TADF) OLED**~~
31. **Explain the operation of a two-layer polymer OLED cell.**

If a voltage is applied between electrodes: A current of electrons flows through the organic layers (cathode → anode) Electrons and holes are attracted towards each other by electrostatic forces An electron and a hole may recombine → exciton in a singlet state or triplet state Depending on the type of emissive material, decay of the singlet state or triplet state releases the extra energy as a photon

32. **Explain the operation of a bottom-emitting polymer OLED display.**

A bottom-emitting OLED display includes a reflective top cathode, usually made of an aluminum compound or lithium fluoride(LiF), and a transparent bottom anode, usually made of indium tin oxide (ITO). The light flows through the anode and, in an active-matrix display, through the active backplane. With this design, the light flow is limited by the transparency of the anode and also by the driver circuitry of the backplane which blocks out part of the light.

33. **Draw the structure and explain the operation of a passive-matrix OLED display.**

In a passive-matrix OLED (PMOLED) display, a cell (sub-pixel) is defined by the area at the intersection of linear electrodes representing the cathode and anode, which are oriented perpendicularly to each other, in a row and column formation. The electrodes are deposited on each side of the organic layers. There are drivers attached to each electrode for applying a certain voltage to the electrodes. A PMOLED display is driven sequentially, one line at a time. At a certain time, all the lines are turned off, except for the line currently being driven. While a line is driven, a certain voltage is applied to each column electrode, depending on the image to be displayed. Each voltage generates a certain current flowing through the organic layers of each cell on the selected line. The brightness of each cell is proportional to the current generated. Unlike liquid crystal displays, which are voltage- driven, OLED displays are current-driven, and this makes them susceptible to current variations. These variations are compensated using special circuitry.

34. **present the addressing circuitry required for each sub-pixel of an active-matrix OLED display(AMOLED)**

Array of thin film transistors (TFTs) At least two transistors and a storage capacitor are needed for each sub-pixel
First TFT: charges the storage capacitor
Second TFT: provides a correct voltage
Advantages: higher refresh rates; higher luminosity; reduced power consumption; displays are not limited in size

35. ~~**Present the semiconductor materials that can be used in the thin-film rs (TFrs) of active-matrix OLED displays.**~~

36. **Explain the white-emitting OLED with color filters (WOLED-CF) color generation technique for OLED displays.**

The white-emitting OLED with color filters (WOLED-CF or WRGB) technique has been originally developed by Eastman Kodak. With this technique, the emitter layers are deposited over the entire area of the display panel, without any patterning. Two or three emitter materials are deposited uniformly to create white light, and then color filters are applied over the emitter materials. The color filters patterned into individual red, green, and blue sub-pixels. An additional non-filtered white sub-pixel is also included, to increase the brightness of the display and to improve its efficiency. The white light can be created by stacking either two or three layers of emitter material.

37. ~~**5.37. Explain the blue-emitting OLED with color converters technique usedfrrcolor generation in OLED displays.**~~

38. **Explain the principle of stacked OLEDs (SOLEDs).**

In a stacked OLED, there are no conventional sub-pixels; each pixel contains red, green, and blue emitters that are stacked vertically rather than being positioned side-by-side. The emitters of a pixel are separated by transparent intermediate electrodes. The potential advantage of this technique is a significant increase of the resolution. Since blue emitters usually have the shortest lifetime, in order to avoid the color shift that may occur when the luminance of these emitters decreases, some stacked OLEDs use alternating blue emitters and stacked red/green emitters. This arrangement of the emitters enables to reduce the current density in the blue emitters and to increase their lifetime. In another arrangement, a white-emitting OLED is added on top of the emitter stack which enables to reduce power consumption and to improve the color reproduction.

39. ~~**5.39. Present the vacuum thermal evaporation technolog- for manufactur-ing OLED displays.**~~

40. **Present the color patterning with shadow masks for manufacturing OLED displays.**

For direct-emission OLED displays, the most widely used technology for sub-pixel color patterning consists of using a pre-patterned shadow mask, typically made of a thin metal sheet, which is known as Fine Metal Mask (FMM). The distance be-between the slits of the shadow mask corresponds to the pixel pitch (distance between sub-pixels of the same color). The shadow mask is made as thin as possible to minimize undesirable shadow effects. For instance, shadow masks with a thickness of 30 um are typically used for OLED displays with pixel densities higher than 200 pixels per inch (PPI). Shadow masks for OLED displays are conventionally patterned through processes such as chemical etching or electrodeposition.

41. **Present the inkjet printing technology for manufacturing OLED displays**

The inkjet printing technology is used for direct-emission OLED displays to deposit polymer OLED materials which are soluble in a solvent. The solutions containing red, green, and blue organic

emitters are dispensed onto a substrate using an equipment that is similar to a standard inkjet printer. When an electric voltage is applied to a piezoelectric crystal, it suffers a mechanical deformation. The inkjet printing equipment includes three reservoirs containing solutions with the organic emitters. A disk-shaped piezoelectric crystal is placed at the back of each reservoir. The crystal is deformed when an electric voltage is applied to it, producing a pressure that expels a droplet of solution out Of an inkjet head (nozzle). The inkjet nozzles are usually arranged by tens in a row The droplets containing a few picolitres of solution can be deposited relatively accurately on the substrate, with a positional accuracy of around 5 gm ever, a slight deviation of the droplet is likely to occur, leading to a positional error that can be large compared to the sub-pixel size. This problem is solved by patterning the substrate with polyimide banks built up around each sub-pixel area, forming a bottom is the sub-pixel electrode. These banks are made hydrophobic (water repellent) to prevent t e re made hydrophilic to ensure the sub-pixels are covered properly. the droplets are dried, the solvent is evaporated, and a patterned film
Is formed

42. **Present the types of flexible OLED (FOLED) displays.**

Conformable(curved) displays are not actually flexible from the user perspective. They can be bent slightly by the manufacturer to place them on a non-flat surface or to create a curved display. However, the end user will not be able to flex the display.

Bendable displays can be flexed by the user. The main difficulty for producing these displays is that they must withstand many bending cycles. In addition, the displays should continue to work while being in the bent state. Other difficulties include the of the devices to enable their displays to bend, which may require other components to bend in addition to the displays, and software support for the bendable displays.

Foldable displays can be folded completely by the user, with a very small curvature radius. This enables new form factors for devices, such as smartphones that open into tablets, or smart bands that open into smartphones.

Rollable displays enable new device form factors, such as a set that WIIS up into a small cylinder, or a tablet-sized device that rolls up into a pen. The world's first rollable OLED set is the LG Signature OLED TV R, announced by LG Display in early 2019 (Figure 5.102). It has 4K resolution and a 65-inch screen. The n set can roll up into its base, and it has three viewing options, full view, line view, and view. In line view, only part of the screen is showing, and the set can display different options, including weather, clock, and a home dashboard. In zero view' Several display producers are developing smaller rollable OLED displays for screen is entirely rolled into its base. mobile devices. For instance, in 2016 Samsung Display demonstrated a rollable inch OLED display, which features Full-HD resolution and a curvature radius of 10 mm

43. **Present the PenTile sub-pixel layout used for OLED displays.**

The PenTile layout is inspired by peculiarity of the human retina, which contains fewer sensors for perceiving blue colors. This does not significantly affect the perception of luminance, and therefore it is expected that by reducing the number of blue sub-pixels in a display, the image quality will not be reduced. This layout uses Proprietary algorithms for sub-pixel rendering, which are embedded in the display driver. Any input pixel of the image to be displayed is mapped to a logical pixel, which is either a red-centered or a green-centered logical pixel.
There exist RG-B-RG, RG-BG(human eye is more sensitive to the green color) layouts

44. **Present the Diamond Pixel sub-pixel layout used for OLED displays.**

Another sub-pixel layout, called Diamond Pixel, has been introduced by Samsung in 2013. In a display with Diamond Pixel layout, there are twice as many green sub-pixels as there are blue and red ones. The green sub-pixels are oval in shape small, while the red and blue ones are diamond-shaped and larger (the blue sub-pixel is slightly larger than the red one). According to DisplayMate

Technologies, this is because the green OLED emitter is the most efficient and it has the longest lifetime, while the blue emitter has the shortest lifetime. The diamond shapes were chosen to maximize the sub-pixel packing and to achieve the highest possible pixel densisties. The green sub-pixels are oval because they are squeezed between the larger red and blue ones

45. **Present the advantages of OLED displays.**

- High contrast ratio(both static and dynamic)
- Wide viewing angles with no color shifting(because the sub-pixels of OLED directly emit light)
- Wide color gamut and good color reproduction
- Fast response time(no ghosting or trailing problems for dynamic images)
- Thin and light especially when plastic substrates are used
- Low power consumption when dark colors are displayed

46. **Present the disadvantages of OLED displays.**

- High cost of manufacturing
- Lifetime of organic materials is limited and all OLED materials degrade over time(blue are especially problematic)
- Color balance changes over time
- Suffer from image retention called burn in
- Increased power consumption on white backgrounds
- Visibility in outdoor conditions

47. **Draw the structure and explain the operation of a microencapsulated electrophoretic e-paper display.**

Microencapsulated electrophoretic displays have been initially developed by Barrett Comiskey, Joseph Jacobson, and their colleagues at the Media Laboratory of MIT, who later founded E Ink Corporation. They created microcapsules that encapsulated microscopic black and white pigment particles in a clear liquid, which they called "electrophoretic ink" or "e-ink". The black particles are negatively charged, and the white particles, usually made of titanium dioxide (Ti02), are positively charged. The electrophoretic ink contains millions of microcapsules, each about one micrometer in diameter. The microcapsules are suspended in a carrier solution of hydrocarbons and black dye, and the entire structure is laminated into a plastic film for protection. The electrophoretic ink has an overall thickness of around 80 gm, which is only twice that of ordinary paper.

48. **Present the advantages and disadvantages of electrophoretic e-paper displays**

Advantages	**Disadvantages**
• **Have the same readability as normal paper** • **Low power consumption** • **All components can be made flexible**	• **Difficult to build full color displays** • **Low refresh rate**

49. ~~**5.49. Explain the principle of electrowetting e-paper displays.e-paper**~~

50. **Explain the principle of interferometric modulator technology used for e-paper displays**

The interferometric modulator (IMOD) display technology' is an example of bio-mimetics, which is the imitation of nature for a technological solution. This technology is based on the principles of structural color, which can be found in many examples in nature, such as peacock feathers, beetle thoraxes, and seashells. Structural color is formed from the diffraction of light waves off a nanoscale structure, rather than from the absorption and reflection of white light by a colored pigment. Iin structural color, natural light is diffracted by a surface, and the various wavelengths of these component colors in the light are reflected away at different angles. Some of these wavelengths interfere with each other and are cancelled out, while others do not interfere and remain. The resultant is visible color from those wavelengths that were not cancelled out by this interference

51. **Draw the structure and explain the operation of an optical cavity used in interferometric modulator e-paper displays.**

Optical cavity consists of a deformable reflective membrane residing on a bottom substrate covered by an electrode, and a thin-film stack residing on a transparent top substrate. The reflective membrane and the thin-film stack, both acting as micro mirrors of the optical cavity, are separated by an air gap. The deformable membrane is used to adjust the geometry of the cavity, which serves as a pixel (or sub-pixel) of the display. When ambient light reaches this structure, it is reflected both off the reflective membrane and off the top of the thin-film stack, which is semi-transparent. Depending on the height of the cavity, light of certain wavelengths reflecting off the membrane will be slightly out of phase with light reflecting off the thin-film stack Therefore. some wavelengths constructively interfere, while others destructively interfere, depending on the phase difference. As certain wavelengths will be amplified by constructive interference with respect to others, the human eye will perceive a certain color corresponding to those wavelengths. Destructive interference results in black color. The light reflected by an optical cavity can be switched between a certain color and black by changing the state of the deformable membrane. The default state of the membrane is the open state, when it is close to the electrode and bottom substrate.To switch the state of the membrane, a voltage is applied between the thin-film stack and the electrode on the bottom substrate. Then, electrostatic forces attract the deformable membrane towards the thin-film stack, which is the collapsed state of the membrane. This changes the height of the optical cavity, which results in destructive interference. The consequence is that almost all incident light is absorbed, and the optical cavity will appear black to the viewer.

52. ~~**the technologies that can be used for fill-color electrophoretic**~~

53. **Present the Advanced Color ePaper (ACeP) technology.**

Acep uses the CMY color system, which, for reflective is more efficient than the RGB color system. The ACeP technology uses a single electrophoretic layer, unlike other multi-pigment systems that use a multi-layer(stacked) structure in which the three pigment layers are provided with their own array of addressing electrodes. The single-layer structure simplifies the display and reduces the manufacturing costs. The electrophoretic layer contains three transparent. Colored pigments (cyan, magenta, and yellow), which are the subtractive primary colors. In addition, the layer contains an opaque white pigment, which reflects the light. All primary colors can be created by mixtures of these four pigments. Additional pigments can also be included to enhance particular colors such as black, which is a composite of cyan, magenta, and yellow. Therefore, a more complex system may also include a black pigment, but then the difficulty of separating the pigments will increase. Two of the pigments are positively charged, and two pigments are negatively charged. The ACeP technology is based on selective electrophoretic mobility pigments and involves "racing" between these pigments. Such pigment racing is complicated by the fact that the motion of charged pigments changes the local electric within the electrophoretic fluid. In addition, the mobility of certain pigments maybe voltage-dependent. Although the ACeP technology' takes advantage of pigmenting, this effect on its own is not enough to ensure full control of the color

54. -

55. **Present the color interferometric modulator technology for e-paper displays.**

Color generation in a display that uses the interferometric modulator (IMOD) is achieved by adjusting the height of the optical cavities that represent the sub-pixels of the display. For each height, light with a certain wavelength is emitted when the optical cavity is in the open state, and thus constructive interference. Color generation through interference is much more efficient than traditional methods that use color filters and polarizers, which absorb much of the light entering the display. In a color IMOD display, the height of each optical cavity is tuned to the wave- of either the red, green, or blue color. A full-color IMOD display contains spatially ordered optical cavities that correspond to the red, green. and blue sub-pixels. Since each optical cavity is either black when it is in the collapsed state or reflects a certain color certain color when it is in the open state, to create different shades of the colors, some type of dithering is needed. When spatial dithering is used, pixel is divided into a number of smaller addressable elements. This sub-division requires a separate row driver for each sub-pixel group of sub-pixel elements. By activating various combinations of sub-pixel elements at a certain time, it is possible to control the average intensity of each green, and blue sub-pixel. However, the number of colors that can generated though spatial dithering is limited.

56. **Present the photo-emissive quantum dots.**

When photo-emissive QDs are illuminated by visible or ultraviolet light, the electrons inside atoms receive an extra energy(they are excited) and some of them may break free from the atoms. This enables the to move freely through the material and to create what is known as a conductance bamd. In which electrons conduct electricity. When these electrons return to the outer orbital around the atom, which is called valence band, they emit light with the same energy that the electrons originally absorbed. The color of the light emitted(its wavelength and frequency) depends on the energy difference between the conductance band and valence band(the bad

57. **Explain the principle of Quantum Dot Enhancement Film (QDEF) technology.**

Unlike regular LCD panels that commonly use a white backlight generated with "white" LEDs (which are actually blue LEDs with yellow phosphor to give the impression of white light), QDEF panels use a blue backlight generated with blue LEDs. The blue backlight is not only used to create the blue primary color, but also to supply the energy required for the photo-emissive QDs that will emit light. The blue LEDs are arranged in an array or at the edges of a plastic light guide plate (LGP). The LGP is a plastic sheet that guides the light emitted by the blue LEDs through a dotted pattern, so that the light runs through the entire sheet. On the back of the LGP there is a reflection sheet, and in front of it there is a QDEF sheet, which replaces the diffuser sheet that is used in regular LCD panels. The QDEF sheet contains QDs that emit pure red light and QDs that emit pure green light. This sheet, with a thickness between 50 gm and 100 prn, consists a layer of QDs mixed with resin, encapsulated between two thin barrier films. The red and green primary colors emitted by the QDs are mixed with the blue primary would of the backlight using optical films, to create a much purer white light than it would be possible by using white LEDs. Then, this white light is passed through the same layers as in a regular LCD panel: the first light polarizer, the TFT layer needed for the active-matrix pixel addressing, the liquid crystal layer, the color filters and the second light polarizer

58. **Explain the principle of Quantum Dot on Glass (QDOG)**

QDs reduce the thickness of the display panel. The layer containing film mixed with resin is coated directly onto the glass LGP and is covered with a thin film made by using inexpensive technology, which may be the same thin film encapsulation technology use for OLED displays. This eliminates the need for expensive barrier films that are used with the QDEF technology.

59. **Explain the principle of Quantum Dot Color Conversion (QD-OLED) technology.**

- **Color filters are still needed by the previous technology which reduces brightness**
- **QDCC replaces the color filters with a layer of QDs patterned into sub-pixels**
  - **Blue sub-pixels are transparent to allow passing the blue backlight**
- **QD depolarizes the light**
- The viewing angle is improved by moving the emissive QDCC layer to the front

Technologies for creating the QDCC layer

- Photolithography: high rate of QD wastage
- Ink-jet printing: cost is reduced

60. **Explain the principle of Quantum Dot on OLED (QD-OLED)**

- Uses a layer of quantum dots patterned into sub-pixels for color conversion(QDCC)
- The blue backlight is generated with a blue OLED emitter stack
- The liquid crystal layer is eliminated
- The display becomes fully emissive
- ADV:
  - Color gamut is extended compared to WOLED
  - Structure of WOLED displays is simplified
  - The manufacturing costs are reduced

61. **Explain the principle of Quantum Dot on MicroLED (QD-MicroLED technology)**

- For each subpixel there is a microLED
- Image retention is eliminated, higher brightness, higher energy efficiency
- When the size of LED is reduced -> reduce amount of light
- Possible approach to reduce complexity: only use blue microLEDs(color converters are used for red and green, QDs can be used as color converters)
- Technical challenges:
  - QDs are exposed to high temperature -> degradation

62. **Explain the principle of Quantum Dot Electro-Luminescent technology.**

- **Uses electro-emissive QDs**
  - **Similar to OLEDs**
  - **Inorganic materials placed between electrontransporting and hole-transporting layers**
  - **Same function as that of a conventional LED or microLED**
  - **More susceptible to damage than photo-emissive QDs used as color converters**
  - **Currently stability is poor**
- **Adv:**
  - **high brightness**
  - **Very efficient**
  - **Low cost of manufacturing**

Chapter 6

1. **Draw the structure of a graphics adapter and explain the functions of its components.**

The main function of a graphics adapter (also called graphics card or display adapter) is to generate images for a display device. Many graphics adapters offer additional functions, such as accelerated rendering of 2D and 3D graphics, video decoding and encoding, or the ability to connect multiple displays. A graphics adapter can reside on an expansion card that is inserted into an expansion slot, or it can be integrated into the motherboard CPU chip, or system-on-chip(SOC).

2. **Present the main components of a GPU and explain the operations performed by these components.**

- **Video BIOS:** contains a basic firmware for initializing the graphics adapter. It also contains information on the **graphics memory timing**, **operating frequencies** and **voltages** of the GPU, and other parameters
- **Graphics processing unit:** implements the main functions of the graphics adapter. It commonly includes a bus interface, 2D engine, video engine, graphics memory controller, cache memory, 3D graphics engine
- **Graphics memory:** contains the framebuffer that holds the image
- **Display interface:** VGA, DVI, HDMI, Display port

3. **Explain the difference between single-ported and dual-ported graphics memories.**

Single ported	**Dual ported**
• The unique data port is used for refreshing the screen and for writing new data	• One of the ports is used for updating the images in memory • The second port has serial access and is used for refreshing the images on the screen

4. **Explain the difference between the Quad Data Rate (QDR) and Double Data Rate (DDR) operation modes of the GDDR6 memory.**

Quad Data Rate	**Double Data Rate**
• The frequency of WCK signals is doubled internally(doubles data rate without the need to increase the frequency)	• F wck is not doubled(reduces power consumption while limiting rate)

5. **Explain the following techniques used by the GDDR6 memory: data bus inversion, command/address bus inversion, signal training, and calibration**

Data bus inversion: reduces the no of zero bits transmitted if more than 50% are zero it inverts them because transmission lines have high-level termination -> power dissipation is reduced
Command/address bus inversion: similar to data bus inversion and it refers to all command and address(CA) lines
Signal training: Phase adjustment of clock, data, and address signals

- **Address training**: alignment of address lines to the CK signal
- **Data training:** alignment of the data lines to the corresponding WCK signal Alignment of each WCK signal to the CK signal A "hidden" data re-training is possible

Calibration: improves reliability of data transmission. Auto-calibration determines the drive strength and termination impedance, which compensates for process variations during manufacturing and temperature variations during operation

6. **Present the power-management features provided by the GDDR6 memory.**

- Scalable clock frequency
- Low power mode for DRAM core
- Increasing the termination impedance at slower data rates
- Self-refresh and hibernate self-refresh modes
- Low supply voltage
- Data and address bus inversion

7. **Draw and explain the structure of High Memory (HBM).**

Consists of 1 or more memory stacks(up to 8,12,16 DRAM dies). Connection to a CPU/GPU/SoC via physical interfaces and a silicon die. Memory stacks cpu/gpu/soc die, and silicon die are encapsulated in a single package

8. **Present the main features of the first, second, and improved second gen of High Bandwidth Memory.**

1st gen	2nd gen	3rd gen
• 1.3V, 500MHZ • 1GT/s per line transfer rate • Each DRAM die communicates via 2 128 bit channels • Memory capacity up to 4GB per device	• 1.2V 1GHZ • 2GT/s per line • 256GB/s • 8GB max capacity	• 3.2GT/s per pin • 409.6GB/s per memory • 24GB per device

9.
10.
11.
12.
13.
14. **Present the vertex shaders, geometry shaders, and pixel shaders of a GPU**

Vertex shaders:
- Operates on individual vertices of primitives (points, lines, triangles)
- Used to modify or create values associated with each vertex: position, color, texture
- Implements geometry processing operations
    - Model transform: translation, rotation, scaling
    - View transform: positioning the view camera at the origin of the coordinate system
    - Lighting: determining the effect of light sources on an object's material

Geometry shader
- Enables to convert primitives into other primitives
- Inputs: vertices for a single primitive
- Outputs: zero or multiple vertices forming a single topology (e.g., triangle strip)

Pixel shader
- Performs shading computations on each pixel
- Inputs: results from the vertex shader, interpolated by the triangle traversal stage
- Outputs: color, opacity value, and depth value for a pixel
- Texturing: changing the appearance of a surface using a texture image or function

- Texture filtering: reduces unwanted effects when a texture is smaller or larger than the pixel area being textured

15. **Present unified shaders of a GPU**

Instead of using separate shader cores for vertex processing, primitive processing, and pixel/fragment processing, a unified shader architecture provides a large array of computing units general enough to perform various shading operations.

- Contain dynamic scheduling and load-balancing unit that distributes the shading operations to the computing units.
- Offers flexibility: when a graphics application needs to draw intercate charaacters and objects which requires to perform many geometry computations the scheduling unit can allocate vertex and geometry shader tasks to most of the compute units

16. **Compare dedicated and integrated GPUs.**

dedicated	**Integrated**
• Offer the biggest performance • Can be upgraded	• Can be embedded into the motherboard as part of the chipset or on the same die as the CPU • - lower bandwidth memory which limits the performance

17. ~~6.17. Present the rendering pipeline and computation pipeline defined by the Direct3D specification.~~
18. ~~6.18. Present the features provided by the Direct3D specification for performing general-purpose computations.~~
19. **Explain the main concepts introduced by the Vulkan API.**

- Full advantage of modern GPUS and multi-core CPUs
- Offers better support for multithreaded CPUs and reduces the load on the CPU
- Supports almost all the major OSs

20. ~~6.20. Present the synchronization primitives provided by the Vulkan API.~~
21. ~~6.21. Present the main differences between the Vulkan and OpenGL APIs.~~
22. **Present the most common graphics commands implemented by the 2D graphics engine of a GPU.**
23. **Describe the tessellation stage of the GPU logical pipeline and explain the advantages of using hardware-implemented tessellation.**

Tessellation

- Enables to render curved surfaces
- Converts the description of a high-order surface into a set of triangles
- Advantages:
    - The description of a curved surface is more compact
    - Saves memory and reduces the bandwidth
    - Enables scalable rendering techniques → level of detail dependent on the position of the camera

24. **Present the operations performed by the output merger stage of the GPU logical pipeline.**

Output merger

- Combines the pixel color with the color currently stored in the color buffer
- Also called raster operations pipeline (ROP)
- Performs visibility tests using the z-buffer
- For each pixel, a transparency (alpha) value is also stored
- The color buffer stores an RGBA (RGBα) color and alpha value for each pixel
- **Alpha blending:** mixing a transparent object's color with the color of the object behind it

25. **Explain the differences between the GPU architecture and CPU architecture.**

GPU	CPU
• **Optimized for throughput** **Throughput: no of operations performed in a given time** **Has thousands simple processing cores** • **High throughput, high latency**	• **Optimized for latency** **Latency: delay from initiating a command until its effect becomes detectable** • **Has a few processing cores** • **Dedicates a large area for cache memories** • **Implement: instruction pre-fetching, branch predition** • **Low latency low throughput**

26. **Draw the structure and explain the components of a typical GPU shader core.**

The basic shader core is the CUDA core. It contains a 32 bit floating point(fp32) unit and a 32 bit integer(INT32) unit.

27. Draw the structure and explain the components of a generic GPU multiprocessor.

28. **Present examples of general-purpose programming languages developed to support GPU computing.**

- Brook
- Accelerator

29. **Present examples of GPU accelerated libraries developed by NVIDIA for deep learning applications**

- CUDNN
- nvGRAPH
- OpenCV

30. **Present examples of GPU accelerated libraries developed by NVIDIA for parallel applications**

- CUDA
- Open CL

31. **Explain what a kernel of Compute Unified Device Architecture(CUDA) is**

Specific C functions called kernels Executed N times in parallel by N CUDA threads At kernel definition, its execution configuration must also be specified Each thread that executes the kernel is assigned a unique thread ID

32. **Present the thread blocks and grids of thread blocks of CUDA**

Thread blocks are organized into a grid of thread blocks. The execution configuration of a kernel includes the number of blocks per grid Threads of a grid access a global memory Execution of the hierarchy of threads Thread: executed on a CUDA core Thread block: executed on a Streaming Multiprocessor (SM) Grid of thread blocks: on an array of SMs

33. **Present the memory spaces that may be accessed by CUDA threads**
34. -
35. -
36. -
37. -
38. -
39. -
40. -
41. **Present the components of a single-link HDMI system.**

- Consists of a HDMI transmitter and receiver
- Contains 3 TMDS data channels and one TMDS clock channel which are used to carry video, audio and auxiliary data
- Each channel is using differential signaling and is implemented with a pair of twisted wires

42. **Describe the TMDS link between a TMDS transmitter and a TMDS receiver**

- 3 data channels, 1 clock channel.
- It provides a clock rate proportional to pixel rate of the transmitted video data
- 3 identical encoders/serializers to which the input streams are applied

43. **-**
44. **Present the functions of the Display Data Channel (DDC) used by HDMI**

- provides bidirectional communication between computer and display and allows for automatic system configuration
- Also used for High bandwidth digital content protection which helps with protecting against altering the signal

45. ~~Explain how the messages are sent on the Consumer Electronics Control(CEC) bus of HDMI~~
46. ~~Present the end-user features and supporting features enabled by the CEC bus of HDMI~~
47. **Present the improvements introduced by version 2.1 of the HDMI specification**

- Increased bandwidth(48Gbits/s)
- 10K resolution
- 4Kx2K(120Hz); 8kx4K(60hz)
- Variable refresh rate
- Quick frame transport feature(reduces latency of frames -> interactive virtual reality)

48. **Present the components of a DisplayPort link**

- Consists of and a Hot Plug Detect signal line
- **main link(unidirectional)**: carries isochronous data streams such as uncompressed video and audio streams
- **auxiliary link:** half duplex bidirectional channel used for link management and device control
- **Hot Plug Detect**: used by the source to detect the presence of a sink device. Also an interrupt request by the sink device to the source device

49. **Describe the services provided by the auxiliary channel of the DisplayPort interface**

- Transfers device management and device control data for the main link(aux data such as usb)
- Data is performed through a series of burst transactions

50. **Present the improvements introduced by version 2.0 of the Display Port specification**

- 20Gbits/s per lane
- Thunderbolt physical interface
- Display stream compression

51. **Difference between protocols used by the Display Port and Embedded DisplayPort interfaces**

Display Port	**Embedded Display Port**
• At power-on the DP interface performs full link training protocol • Only MCCS command set • Only StandBy and Power Down • Has HDCP	• Can be configured to perform fast link training or no link training • Additional commands through AUX channel • Allows to adjust the display timing depending on the images displayed • Only has ASSR

52. **Present Panel Self-Refresh feature of Embedded display port**

- A video frame buffer is added to the display controller which enables to maintain a static display image without receiving video data from the GPU
- GPU sends signal and freezes the image on screen until it detects a change

53. **Advantages of embedded display port over LVDS**

- It provides all panel connections including data, control and power signals in a single connector
- Reduces amount of cable
- Can use an existing DP GPU interface without separate video port
- Electromagnetic interference is reduced
- Overall system power consumption is reduced

Chapter 7

1. **Explain the goals of data encoding used for compact discs.**

- **High information density:** makes the best possible use of the high but limited resolution of the laser beam and the read assemby
- **Minimum inter-symbol interface:** make the minimum run length as large as possible(consecutive 0 or 1 bits)
- **Avoiding a separate timing track:** the data should be encoded so as to allow the clock signal to be regenerated from the dta signal. Limit the maximum run length of the data so that data transitions will regenerate the clock signal

Straightforward would be to represent bits of 0 as lands and 1 as pits but this does not respect ether of the goals

2. **Explain the principle of Non Return to Zero Inverted (NRZI) coding.**

- A bit of 1 is recorded as a state change of the medium(as a transition from a pit to land)
- A bit of 0 as the absence of state change of the medium(indicates continuation of pit or land)

3. **Explain the Eight-to-Fourteen Modulation (EFM) coding used for compact discs and the requirements satisfied by EFM codes.**

There are many more combinations of 14 bits than there are combinations of 8 bits. To encode 8 bit combinations 256 combinations of 14 bits were chosen that satisfy the requirement to avoid very short and very long runs of successive zeros. To avoid 2 successive bits of 1 between 2 adjecent EFM code sequences 3 merging bits are inserted after each sequence of 14 bits which are discarded when read

4. **Draw and explain the structure of a compact disc recording system.**

5. **7-5. Explain the Cross Interleaved Reed-Solomon Code (CIRC) error detection and correction system used within the frames of compact discs.**

Cross interleave component breaks up the long error bursts into many short errors and the Reed-Solomon components provides the error correction

6. **Explain what a sub-channel of a compact disc is and what the sub-channels are used for.**
7. **Explain the following concepts related to compact disc organization:**

- Track: partition of the dish address space
- transition area: between the tracks encoded with different types of information
- lead-in area: the designated track zero but is not addressable through the drive command set
- lead-out area: designated 0xAA but is not addressable through the drive command set
- index: a partition of track. Pre gap areas are encoded with 0

8. **Draw the structure and explain the operation of an optical read assembly.**

Laser diode generates a low power lase bream. The beam passes through a unidirectional reflecting mirror, is directed with a collimator lens and is focused onto the disc surface with an objective lens. The laser is positioned precisely on the right track with servomechanism that includes a servomotor. Part of the beam is reflected back by the disc surface. The amount of reflection determines if pit or lane

9. ~~**Present the main features of the following Compact Disc-Digital Audio(CD-DA) variants: CD+G, CD+MIDI, and CD TEXT**~~
10. ~~7.10. Present the main features of the Super Audio Compact Disc (SACD)format.~~
11. ~~7.11. Explain the Direct Stream Digital (DSD) technology used to encode the audio waveform on Super Audio Compact Discs.~~
12. **Explain the principle of data recording on Compact Disc-Recordable(CD-R) discs.**

- Several photosensitive dyes
- The laser heats certain areas to 250'. In the heated areas the oganic dye changes its chemical composition. These burned areas with changed chemical composition reflect light to a lesser degree and they emulate the properties of pits

13. **Explain the functions of the spiral groove used on CD-R discs.**

Spiral groove is similar to the spiral on which the data are recorded on regular CDs. The microscopic groove is used by the CD-R during recording to follow the data path on the disc. If the disc is unformatted, writing the spiral tracks would be complex

14. **Explain the function of the Power Calibration Area (PCA) and Program Memory Area (PMA) used on CD-R discs.**

(**PCA**)

- o Used to calibrate the laser power → trial recording
- o The optimal power setting depends on: recording speed, ambient temperature, humidity, disc type

PMA

- Contains the track numbers of the recorded titles as well as their start and stop addresses

15. **Explain the writing. erasing, and overwriting operations performed on Compact Disc-Read/Write (CD-RW) discs.**

Writing:

- Rec layer is heated above the melting point
- Crystals get to an amorphous state
- If cooling is fast -> amorphous state is maintained

Erasing:

- Recording layer is heated below the melting point but above the crystallization point
- Temp is maintained for a time longer than the crystallization time

OverWriting:

- New pits are created using the laser beam for writing
- Constant laser beam is used to create new crystalline lands
- Process can be repeated about 1000 times

16. **Present the techniques used by Digital Versatile Discs (DVDs) to increase disc capacity compared to compact discs.**

- Pit size is smaller
- Distance between tracks is lower
- Wavelength of the laser beam is smaller
- Up to 4 layers

17. ~~**Explain the advantages of DVD-Video format over previous disc formats used for video and movie distribution**~~
18. **Main features of DVD-R**

- 2 variants A, G
- A: authoring, intended for professional archiving, disc production
- G: intented for consumer applications, lower cost than A
- Discs are engraved with a spiral groove containing addressing information for blocks(LPP land pre-pit. Pits are engraved between grooves)

19. ~~**Explain Disc-at-once and incremental writing methods that can be used for recording DVD-R discs**~~
20. **Explain the Address In Pre-Groove(ADIP) method used for storing block addresses on DVD+R discs**

- Addressing is based on phase modulation of the wobbles on the spiral groove. With this method the wobbles are shifted in phase to be inverted. Each address bit of 0 or 1 consists of 4 consecutive wobbles, 2 notmal phase wobbles and 2 inverted phase wobble
- Less susceptible to interference and error
- Higher reliability at higher speeds
- Error management is more robust

21. **DVD+R vs DVD-R**

- Control system used for laser tracking is more precise due to higher frequency of the wobbles
- ADIP is less susceptible to interference and defects
- More robust error management
- More accurate linking

22. **Explain how the DVD+ReWritable (DVD+RW) format allows to perform lossless linking**

- High frequency sinusoidal deviation of the groove allows for lossless linking since the slope of a sinusoid at its zero crossing is a function of frequency

23. **Present the techniques used by Blu-ray discs to increase disc capacity compared to DVDs**

- Reduction in the wavelength of the laser(GaN laser diode)
- Increased the numerical aperture of the lens(doubled the capacity)

24. **Modulation technique used by Blu-ray discs**

- A groove is modulated by wobbling. It is a robust technique against distorsions inherent to optical disk(wobble shift, wobble crosstalk)
- Combines 2 wobble systems(MSK based on cosine function and STW based on a combination of cosine and sine functions)

25. **Explain the error correction code used by Blu-ray discs**

- Called Long distance code. ECC block of 64K is protected by Reed-Solomon code. As vurst indicator mechanism a picket code is used. The pickets are protected by a second independent Reed-Solomon code called Burst-Indicating Subcode(BIS)
- BIS data are recored on the disc at frequent and regular intervals so there is a short length of LDC encoded user data between single bits of BIS

26. **Explain the functions of the groove system used by recordable and rewritable Blu-ray discs**

-

27. **Principle of Minimum-Shift Keying and Saw-Tooth Wobble modulation systems used by recordable and rewritable Blu-rays**

MSK: represented by 3 consecutive wobbles and two of them have inverted polarity. These are based on cosine functions instead of sine because this way smooth wave-form connections can be achieved with adjacent wobbles without discontinuous

STW: named because of the shave of the waveforms. These wobbles are based on a combination of cosine and sine functions. There are 2 types of wobbles. One for address but of o and the other for an address bit of 1

28. **Triple and quadruple layer blu-ray discs**

- Only specific to BD-R and BD-RE
- Transfer rates required are higher than for HD movies
- High rotation speeds may be required
- Specifications limit the maximum disc rotation speed to 5000 rev/min

29. **Explain the optical interferences at may occur on multi-layer Blu-ray**

- Caused by signals that are reflected by the recording layers, these interfere with the main signal
- The difference in thickness between the cover layer and the spacer must be > 1 micrometer

30. **-**

31. **-**

32. **resent the main features of the Blu-ray Disc-Read/Only Memory (BD-ROM) physical format**

- specifically for movie distribution
- uses a buffer to transport data from disc

- minimum user data transfers(54Mb/s 2D 1.5x, 72Mb/s 3D at 2x)
- maximum TS transfer rates(48Mb/s, 64Mb/s 3d)

33. **Present the main features of the Ultra HD Blu-ray physical format**

- TL discs 100GB
- Transfer rates required are higher than for HD movies
- Higher rotation speed(5000rev/s)

34. **Present the frameworks provided by the High-Definition Movie (HDMV) mode of the BD-ROM Audio Visual(BD-ROM AV) logical format**

- The multiplexed stream can be extended with individual streams stored separately → are decoded at the same time Features: subtitles, menus, button sounds Playback image: formed by overlaying five independent image planes BD-J background plane Two video planes (primary, secondary): enable picture-in-picture (PiP) playback

35. **Present the features specific to the Ultra HD Blu-ray physical format that are provided by the High-Definition Movie(HDMV) mode of the BD-ROM AV logical format**
36. **Present the features provided by the Blu-ray Disc-Java(BD-J) mode of the BD-ROM AV logical format**

- Extends the HDMV mode's features
- Frame accurate animation
- Interactive audio
- Internet and network connectivity
- Control of local storage devices
- Eg. Games, subtitle updates, playback control