Active learning in optics and photonics – Liquid Crystal Display in the do-it-yourself

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ABSTRACT

Monitors are in the center of media productions and hold an important function as the main visual interface. Tablets and smartphones are becoming more and more important work tools in the media industry. As an extension to our lecture contents an intensive discussion of different display technologies and its applications is taking place now. The established LCD (Liquid Crystal Display) technology and the promising OLED (Organic Light Emitting Diode) technology are in the focus.

The classic LCD is currently the most important display technology. The paper will present how the students should develop sense for display technologies besides the theoretical scientific basics. The workshop focuses increasingly on the technical aspects of the display technology and has the goal of deepening the students understanding of the functionality by building simple Liquid Crystal Displays by themselves.

The authors will present their experience in the field of display technologies. A mixture of theoretical and practical lectures has the goal of a deeper understanding in the field of digital color representation and display technologies. The design and development of a suitable learning environment with the required infrastructure is crucial. The main focus of this paper is on the hands-on optics workshop "Liquid Crystal Display in the do-it-yourself".

Keywords: Educations, Education in Optics and Photonics, Hands-on Optics, Liquid Crystal Display

1. INTRODUCTION

At the Offenburg University a broad supply of teaching events is offered to the students of the faculty Media and Information Engineering and Design to get a cross-media insight into the world of media. It is a good mixture between theoretical lessons, active learning workshops and many practical projects. All theoretical scientific basics are offered and conveyed intensively to realize print products, films, animations, online projects or Apps. A big challenge is the task to be always up to date, because we experience a rapid technological progress in the field of image capturing technologies and display technologies. Hardly any other line of business changes in such a high speed. New technologies, equipment and applications are changing the world of media and the use of media itself. [1] [2]

2. ACTIVE LEARNING IN OPTICS AND PHOTONICS

A mixture of theoretical and practical lectures has the goal of a deeper understanding in the field of digital color representation and display technologies. To understand the underlying ideas, the students need a broad theoretical scientific know-how. Practical tests and exercises are essential to convey and deepen the important theoretical basics. The Students need a practical part to develop a better comprehension. The design and development of a suitable learning environment with the required infrastructure is crucial. Currently offer four workshops regarding these topics in our media lab. The students can be confronted with practical problems. By solving practical problems the students can deepen their theoretical scientific background. [1] [2]

For the workshop "colors and digital display devices" we use the Konica Minolta CRT Color Analyzer CA-100 with the software LabVIEW 5.0. Different tasks introduce the students to the color representation on monitors and displays. In the second workshop "light and color" the spectrometer JAZ from Ocean Optics is used. The JAZ offers much more interesting possibilities. Differently colored LEDs are in the focus of the measurements. In the third workshop "color

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representation on digital display devices" mobile devices with different display technologies for several measurements and evaluations are used. The latest workshop "LCD in the do-it-yourself" is the main topic of this paper. [1] [2]

3. DIGITAL DISPLAY DEVICES

Monitors are the main visual interface for media productions. Their function in production process is very important. Currently, LCD widescreen monitors are typically used in media production. They provide a wide color range. A key criterion is the used LCD panel type. The characteristics of the different LCD panel technologies have a strong influence on the usability for media productions. Today three different panel technologies are used typically in LCD monitors: VA (vertical alignment), TN (twisted nematic), IPS (in plane switching). LCD monitors with IPS panels are best suited, because they provide very low viewing angle dependence. This is an essential factor for the commonly used widescreen monitors. Additionally, IPS panels have a lower brightness contrast than VA- or TN-panels. Other important requirements are the gamut of the monitor, the homogeneity and the temporal and local stability. [1]-[6]

Nowadays mobile devices like tablets and smartphones become more and more important work tools. The use of these devices is a matter of course today. This Trend also extends to the media industry, where tablets have already established a strong presence in the graphic industry. Modern displays become more and more efficient and powerful. This is necessary, because the quality requirements have grown significantly. The preferentially used IPS-LCD technology offer many advantages. Very important is the low viewing angle dependence. Power consumption is very low and the battery life is very good. IPS-LCD technology is very insensitive to touch and enables a very low response time. The color space of different IPS-LCDs looks relatively similar, because they orientate themselves more or less at the sRGB-color space. [4]-[10]

Today more and more AMOLED (Active Matrix Organic Light Emitting Diode) displays are used. They are considerably thinner and have an easy construction. This display type permits quick switching times and can be produced significantly more favourable. Compared to LCDs they offer some advantages like low energy consumption and a very high luminosity. AMOLED displays represent considerably more colors than IPS-LCD particularly in the green range of the light spectrum. [2] [7]-[10]

4. THEORETICAL BACKGROUND

The field of digital color representation and display technologies is broad and so the students need a broad theoretical scientific know-how. To convey this know-how, we work step by step. „From light to the color" includes the scientific theories and knowledge of Newton, Maxwell, Hertz, Young, Brewster, Helmholtz and Hering. „Development of the color representation" contains the CIE human observer and the color-matching functions, the CIE (Commission Internationale de l'Eclairarage) chromaticity diagram, the CIE Lab color space and other color models. „From CIE-Lab color space to color management" continues the way towards the ICC color management, ICC (International Color Consortium) profiles, gamut mapping and rendering intents. The lecture contents are extended with an intensive discussion of different display technologies and its applications. The established LCD technology and the promising OLED technology are in the focus. [1] [2]

4.1 LCD (Liquid Crystal Display)

The classic LCD is now the most important display technology. LCDs are used in all sorts of flat screens and are currently the predominant technology used in mobile devices. The function of this display technology is based on the fact that liquid crystals affect the polarization direction of light, when a defined electrical voltage is applied. A pixel consists of two glass plates which are coated on its facing sides with a transparent electrode layer. In every cell it comes to an interaction of linearly polarized light with a nematic liquid crystal. The liquid crystals which are lined up helically are between the glass plates. Polarization filters are stuck on the outsides of the glass plates. Lighting elements are mounted on the back (so-called backlight). In front of each sub-pixel color filters are affixed. Thus the light of the backlight is let through and inked selectively, completely or partly for every single pixel. The possibility to turn the polarization direction of light is based on the optical anisometropia. This is the determining physical mechanism. [4]-[6] [11]-[13]

There are different panel technologies used to form the color representation of an LCD. Panels with twisted nematic technology have the abbreviation TN. The first polarization filter gives an oscillation level to the light wave. It is rotated along the liquid crystals by 90°, so the light can pass through the second polarization filter. If a voltage is put on, the liquid crystals chains position themselves vertically to the glass tops. The light isn’t rotated any longer now and therefore cannot pass the second glass plate. Panels with vertical alignment technology have the abbreviation VA. In their idle state the liquid crystals are aligned vertically to the glass plates and don't turn the direction of oscillation of the light. When an electrical voltage is applied, the liquid crystals open like gates. Now the light is rotated along the liquid crystals and can pass through the second glass plate. The single pixels are headed about a TFT matrix and so the adjustment of the liquid crystals is controlled. The brightness regulation allows a color mixing and thus the desired color representation. [4] [5] [12]-[14]

A further development is the Super LCD. The display manufacturers have cleared up some weak points here. Among other things, reflections of ambient light are reduced by the fact that there is no more air layer between the display glass and the display layer. A Super-LCD offers also a higher sharpness, better contrast and a wider viewing angle than a classical LCD. The latest LCD technology called Super LCD 2. It is based fundamentally on the so-called IPS displays. IPS stands for "In-Plane Switching" and describes a special technology for LCD’s that improves especially the viewing angle stability. The power consumption of an IPS panel is usually a little bit higher, because for the optimal display representation a brighter backlight is needed. The reaction times are comparatively long, which barely is noticeable in everyday smartphone usage. A Super LCD 2 is very flat. The touchscreen and the Super LCD share the same glass level. The original Super LCD consists of two still separated glass levels which makes the display slightly thicker. [8] [9] [14]

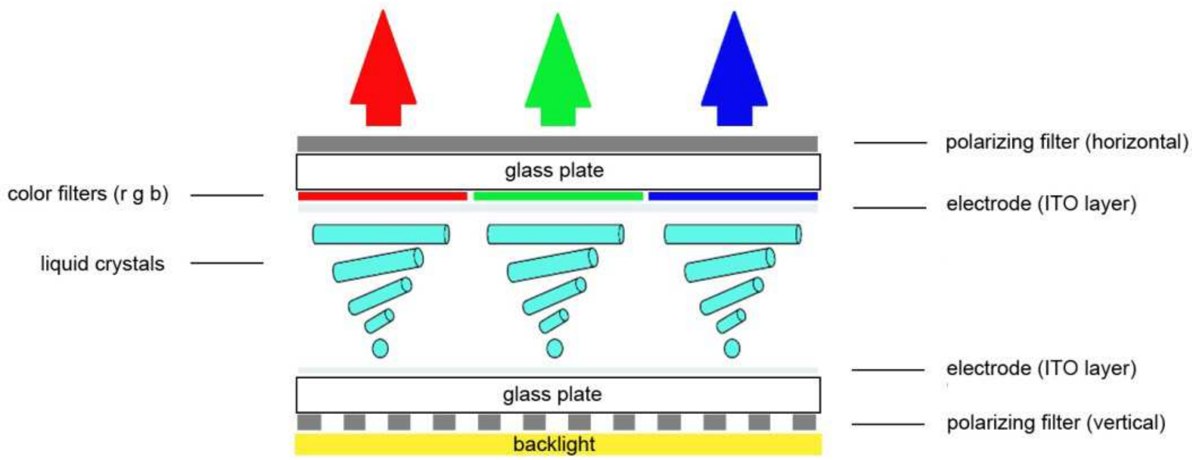

Figure 1. Schematic diagram of the LCD technology [4]-[6]

4.2 OLED (organic light emitting diode)

The OLED technology is based on the fact that certain polymers emit light, as soon as they put in a sandwich from conductive layers, voltage is applied. OLEDs consist of several organic layers with semiconductor behavior. An extremely thin, transparent, electrical conducting layer made of indium tin oxide (ITO) is found on a flexible, transparent strap foil. The real light emitting organic layer follows this, embedded between a hole transport layer and an electron transport layer. Above it come the second electrode (cathode). The OLED shines if electricity flows through this sandwich. [15]-[18]

As every sub-pixel itself becomes the source of light, no background lighting is necessary. Behind the ability to switch on or off the light emission are certain natural combined organic molecules. They have semiconductor behaviors and are therefore suitable for the transportation of electrical charges. The polymers may not get into contact with water or oxygen, because they react with these substances and are destroyed by it. It is necessary to protect the organic elements against external influences by encapsulating the display. [15]-[18]

OLEDs are made of small molecules or polymer materials and need only one single substrate. Therefore, OLEDs can be produced as extremely thin layers. The development of suitable conductive transparent plastic substrates clears the way for flexible displays. Because of the thin-film structure OLEDs achieve excellent visual qualities (high contrast and brilliant colors) and a highly precisely light emission with a low viewing angle dependency. Their energy consumption is very low. [15]-[18]

AMOLED (Active Matrix Organic Light Emitting diode) is an advancement of the classical OLED. The difference exists primarily in the control of the single pixels. The organic light-emitting diodes are controlled in their entirety as active matrix by using transistors. These determine how much electricity is routed to the individual diodes, making them shine brighter or more darker. The color representation seems always evenly illuminated and is virtually independent of the viewpoint. The next step is the Super-AMOLED. Super-AMOLEDs are using the so-called PenTile matrix with the layout pattern red, green, blue, green (RG-BG). This special arrangement ensures that the real resolution remains the same, but a third of the sub-pixels are missing compared to a normal pixel arrangement. Particularly the representation of lines and characters suffers with a PenTile display. The latest development is the Super-AMOLED plus. For these display technology the Pen-Tile matrix is replaced by the Real-Stripe technology. Now every pixel contains the three colors Red, green and blue. The resolution of the display becomes clearly higher and single pixels are not recognizable any more. In addition, the black values were improved, the contrast increased and the battery drain lowered again. [7]-[9] [14]

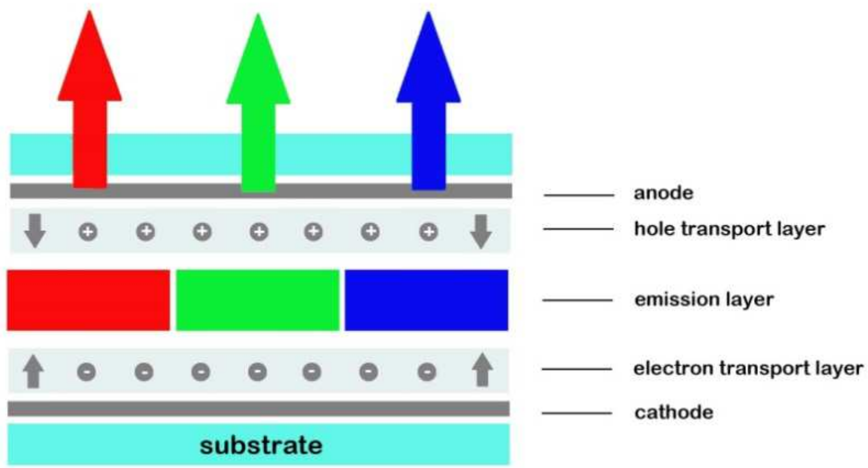

Figure 2. Schematic diagram of the OLED technology [16]-[19]

5. THE WORKSHOP

In the workshop “LCD in the do-it-yourself” the students have to build simple LCDs themselves. The workshop takes five hours. The construction process is divided into different segments. Between the segments, theoretical basics around the LCD technology are repeated. The combination of these theoretical basics with the carried out construction steps leads to a deeper understanding.

5.1 The practical part

The basic materials are two with indium and tin coated display glass plates. The glass plates are cut to a size of 5 cm x 4 cm. The metallic indium and tin appears like a deep brown layer on the glass tops. A custom simple motive has to be transferred to the conducting layer of the two display glass tops. With the help of a digital multimeter the layer side is checked first.

The transfer of the motive is simply practicable. It makes sense to work first with on fitted test foils. So the motive can be placed optimally in consideration of the technical requirements. Simple signs and graphics can be created with a waterproof marker. Every graphic element must be provided with a connection line which leads to the conductor junction area. The motive must be transferred on both glass plates. In the finished display all sectors are connected where the electrodes face each other on both insides of the glass plates. This means the connection lines should not face each other, because they would be usually visible. It is important to check the tightness of the design, since the non-protected places of the conductive layer are removed in an etching bath in the next step.

The electrode structure is covered by the applied motive. The exposed coated surfaces can be etched. An etching bath with 5% hydrochloric acid is used. The exceptionally thin metal layer from indium and tin can be easily etched in hydrochloric acid and is best suitable for the electrode structuring. The glass plates are placed completely in the etching bath and then are swiveled carefully 30 seconds. The end of the etching process is confirmed by the disappearance of the brown color of the coating. Now the glass tops are washed up with water. Then the motive transferred with the waterproof marker must be removed with acetone.

To get transparent glass tops with high conductivity, these must be oxidized. Indium tin oxide (ITO) shows an excellent conductivity and is nearly clear. The oxidation of the metal layer is carried out with high heat in an oven. The deep brown layer decreases during the oxidation process more and more. For cooling, the glass plates are removed from the oven. Then the glass plates have to be cleaned again. The surfaces must be completely free of grease. So the glass plates are cooked in a special alkaline surfactant-free cleaning bath for 3 to 5 minutes. The cleaning bath is brought to cooking under addition by little boiling stones. After the withdrawal from the bath the glass plates may not be touched any more with the fingers. Now they are washed up in distilled water and are laid with the layer side upwards on the worktop. The layer side is checked again with the help of a digital multimeter.

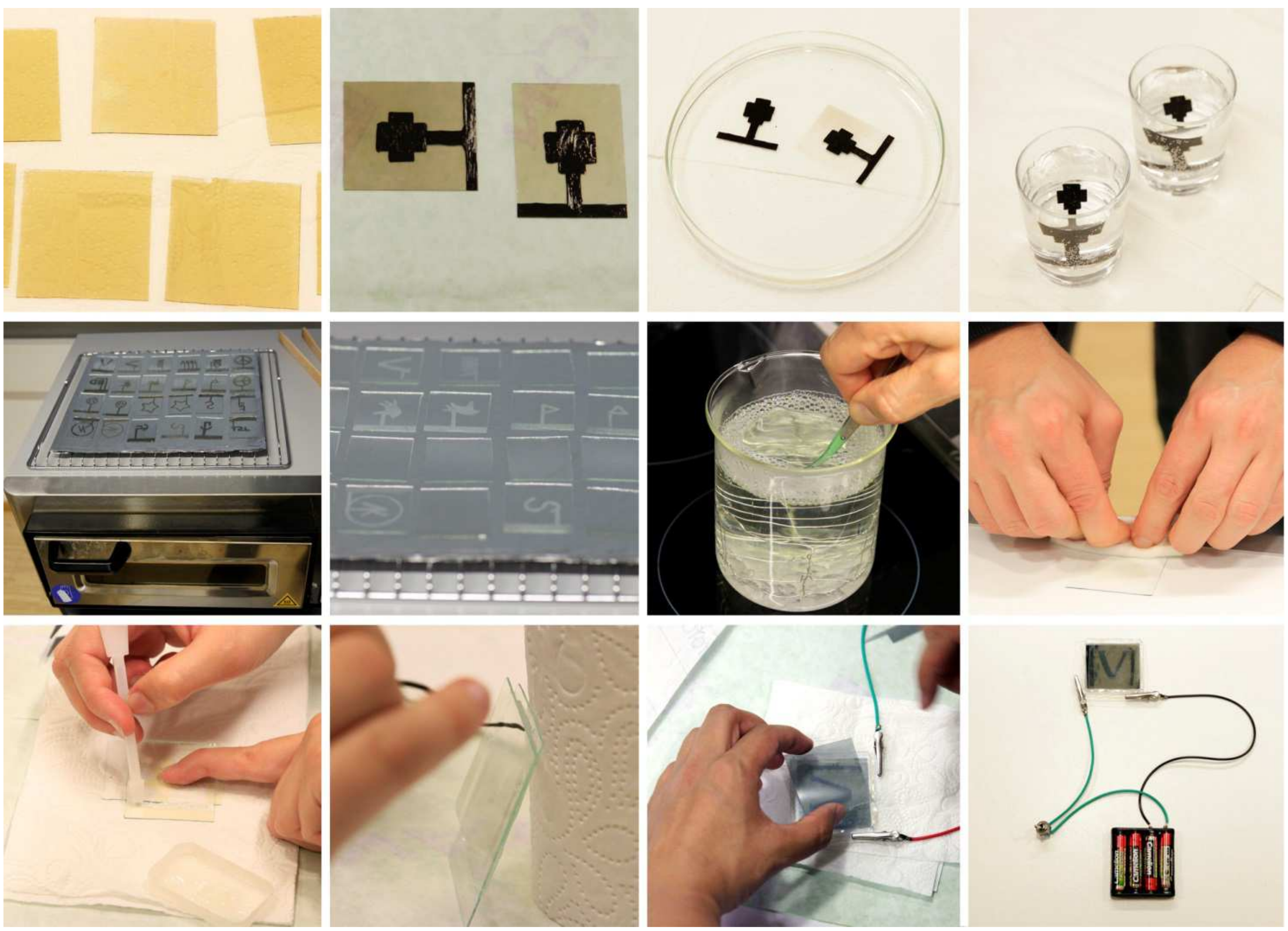

Figure 3. Simple Liquid Crystal Displays in the do-it-yourself

For a functioning liquid-crystal display the liquid crystals must be oriented in defined manner. The orientation of the liquid crystals on the surface of the glass plates would be reached by rubbing with a cellulose cloth. The rubbing process generates microscopic grooves on the surface. The elongated molecules orientate themselves with their longitudinal axis in the generated grooves. The orientation of the molecules towards the upper glass plate must be vertically (90°) to those of the lower. The glass plates should be held in a distance of from 10 to 12 microns. Two distance holders are cut from a foil. These are laid suitably to the motive on the coated side of the lower glass plate. The upper glass plate is raised with the layer side down. Both sides with the distance holders are closed with 2 component glue. During the setting the glass plates should be easily held on. The glue needs 10-minute drying time.

For the filling of the cell with liquid crystals a spatula is used. The liquid crystals are filled drop by drop on one open side. By the capillary effect the liquid crystal automatically spreads between both glass tops. It can be refilled, until the cell is completely filled. Rests of the liquid crystal can be wiped with an absorbent tissue carefully from the edge. Now the cleaned still open sides of the display must be sealed airtight with adhesive. Because the display has no backlight, it must work with incident ambient light. To make this possible, a reflector layer which carries a polarization layer at the same time is stuck on the back. A second transparent polarization foil is stuck on to the front side. Depending on the orientation of the polarization foil the display shows a bright image on a dark background or a dark image on a light background if the voltage supply is applied. A liquid-crystal display is headed with low-frequency alternating voltage. To test the display a tension of approx. 5 V is required.

5.2 The theoretical part

During the Workshop all important theoretical basics of the LCD technology are explained. The technical functionality of liquid crystal displays is in the focus. The opto-electronic features take here an important role. With the help of videos and animations the different panel technologies and their specific qualities are described. The differences between TN-, VA- and IPS-panels are elaborated. Another important technical specification is the used backlight technology. Today LEDs (light emitting diode) are used. The edge LED technology and the direct LED technology are compared with each other. Terms like "local dimming" and "backlight blinking" are explained.

Another main topic are the physical characteristics of liquid crystals. The specificity of the liquid crystal phase is made clear once again. On the example of the Schadt-Helfrich-cell the interaction of linearly polarized light with a nematic liquid crystal is explained. If light falls in such a way that the oscillation direction with that of the director (polarizer) agrees, the polarization level is also turned by 90°. The light follows the twisted molecules and can pass the following analyzer (polarizer). The cell shines bright. Terms like "normally-white-mode" and "normally-black-mode" are explained. But also polarization and the mode of action of polarization filters are illustrated. The way such filters are working is easily shown with a polarization foil and a light source. [12] [13]

6. RESULTS

Workshops are the ideal way for lectures to combine theory and practice. Students need a practical part to develop a better comprehension of the scientific basics. To convey and deepen the important theoretical basics practical exercises are essential. Positive experiences with our four workshops in the field of digital display devices confirm this. The theoretical scientific backgrounds can be deepened very well through the practical exercises. A strong sensitization for important topics like color representation, color management and different display technologies should take place. Very positive results are seen at the end of the series of lectures and workshops. [1] [2]

By working with the most important display technologies, we have managed to convey another important aspect of media technology. These display technologies have a determining influence on the color representation. With the use of different mobile devices, we cope with the strongly changed media usage. We extend the theoretical knowledge base clearly by very important aspects. This advanced knowledge has a positive effect on the various design projects which our students have to produce in the course of the study. A clear sensitization of the students takes place and a deeper understanding is created just in the area of the digital color representation. A broad comparison base is very important especially for cross-media productions. [1] [2]

With our fourth workshop "LCD in the do-it-yourself", we get closer to our aim, to expand the practical education in scientific and production-related form even more. But it is still necessary to improve the learning infrastructure further. With our composite form of theoretical and practical lectures, we achieved very positive results. The students were really excited. The results point the way toward more practical education in a scientific but applied direction. However, the design and development of a suitable learning environment with the required infrastructure and corresponding investments are necessary. [1] [2]

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