LCD Modes for Sustainability and Energy Saving

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Abstract

Energy saving is becoming increasingly important, driven not only by stricter energy labels but also by a growing awareness of sustainability among consumers. Additionally, longer battery life for mobile devices enhances user convenience. Liquid crystal (LC) mixtures made by Merck KGaA, Darmstadt, Germany currently support various LCD modes in the market, with ongoing developments focused on energy efficiency and sustainability. We aim to provide a brief summary of these past and future advancements.

Author Keywords

Liquid Crystal, energy saving, sustainability, low refresh rate, low power consumption, green, refresh rate, UB-FFS, UBplus, SA-VA, C-PS-VA, Merck KGaA, Darmstadt, Germany, EMD

1. Introduction

The improvement in the performance of Liquid Crystal Displays (LCDs) has been a significant driver for liquid crystal developments. While this remains true, a noticeable shift towards a new trend, not primarily focused on performance, has emerged. The increasing number of electronic devices with displays globally, along with a trend toward larger screens, has created a greater demand for energy, which is propelling this development. Devices using AI (Artificial Intelligence) are potentially leading to larger power consumption as well due to increased computing power. This new trend can be described as "energy saving" or, more broadly, "sustainability." Several factors contribute to this trend, including external pressures like energy labels that require products to meet specific energy consumption standards to remain competitive in the market. On top of the need for devices and therefore displays with lower power consumption, there is a motivation to optimize the efficiency of the manufacturing process of the displays as well [1-2].

Merck KGaA, Darmstadt, Germany has co-developed several liquid crystal display technologies in collaboration with display manufacturers [3]. Many of the LCD technologies currently available in the market were designed to enhance performance, thereby improving the image quality of electronic display devices for consumers. Several of these technologies also have the potential to contribute to energy savings in the final electronic devices as indicated in figure 1. This paper will present developments in existing LCD technologies and LCD technologies to come that focus on energy savings.

We will showcase examples of various LCD technologies significantly contributed to by Merck KGaA, Darmstadt, Germany. We have developed or are in the process of developing the necessary liquid crystal materials, additives, and mixtures that enable these specific LCD technologies, overcoming various performance challenges. Key parameters such as reliability, switching speed, contrast, and switching voltages must meet specific targets based on their applications. Most of these developments have been successful, as evidenced by the widespread use of several LCD technologies in the market today. Some technologies discussed in this paper are still in the development phase. Our focus will be on energy-saving here and we will not cover all performance-related advancements of each LCD technology, as this cannot be adequately addressed in a single paper.

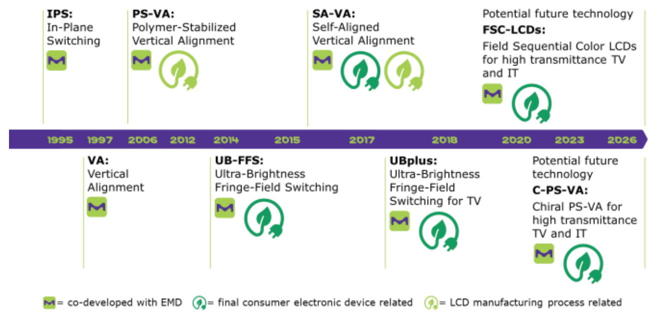

Figure 1. Examples of LCD technologies developed in collaboration with Merck KGaA, Darmstadt, Germany. Several of them can be utilized for energy savings.

PS-VA (Polymer Stabilized Vertical Alignment), an LCD technology that was introduced to the market in 2006 and has since become the dominant choice for television applications. PS-VA utilizes negative dielectric liquid crystal mixtures combined with polymerizable monomers, which are polymerized during manufacturing. This process results in stable alignment and improved orientation of the liquid crystals in the display. The higher transmittance of PS-VA compared to other vertical alignment technologies provides an intrinsic advantage for energy savings in television sets [4-5]. Ongoing developments aimed at enhancing energy efficiency during the PS-VA manufacturing process will be discussed in this paper.

Another important LCD technology is UB-FFS (Ultra Bright-FFS), which is used in mobile, IT, and television devices (referred to as UBplus for TVs). This technology entered the market in 2014 for mobile and IT devices and in 2018 for televisions. UB-FFS is a fringe-field switching (FFS) LCD technology that employs liquid crystal (LC) mixtures with negative dielectric permittivity (-$\Delta\varepsilon$). This configuration results in better transmittance compared to FFS technologies that use LCs with positive dielectric permittivity (+$\Delta\varepsilon$), due to more effective orientation of the liquid crystals in the electric field. Additionally, improved flicker behavior has been observed, leading to further power-saving potential in the final device through the possibility of low refresh rate (LRR) driving without loss of image quality. We will present some developments related to UB-FFS.

SA-VA (Self-Aligned Vertical Alignment) is another LCD technology that was introduced in 2016. It represents the next generation of PS-VA. In addition to a PS-VA liquid crystal mixture, the SA-VA mixture contains specific self-aligning additives, eliminating the need for an additional polyimide (PI) alignment layer in the display. This change leads to energy savings during production and reduces the use of chemicals such

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as solvents for PI solutions. Ongoing developments for television products using this technology will also be discussed here.

Future LCD technologies targeting energy savings are also under development. One such example is the C-PS-VA technology (Chiral Polymer Stabilized Vertical Alignment), which aims to improve transmittance, particularly in high-resolution displays, compared to PS-VA. The current development status of this technology will be presented.

The field sequential color (FSC) display is also an effective method for enhancing transmittance. This approach eliminates the need for color filters by utilizing a time-sequentially driven RGB backlight, which can significantly enhance the transmittance of an LC display [6]. We are actively contributing to a broader adoption of FSC displays in the market. The LC development for FSC will not be discussed here as it is in an early stage.

2. PS-VA – developments for higher LCD manufacturing efficiency

The PS-VA LCD technology is currently the dominant technology for TV displays. Here we want to focus on energy savings in the production process of the display itself. A PS-VA liquid crystal (LC) mixture can be optimized to facilitate a faster and more energy-efficient LCD production process. We have developed new polymerizable materials known as reactive mesogens (RMs), which exhibit a faster polymerization speed. These RMs are crucial for achieving a specific and stable alignment of the LC molecules within a PS-VA LCD. In a PS-VA LCD, the orientation of the LC molecules is typically between 87° and 89° relative to the substrate, rather than a precise 90° orientation. The RMs help establish this stable tilt angle. The polymerization process occurs in two steps using UV light irradiation. In the first, shorter irradiation step, the specific tilt angle is created, while in the second, longer step, the remaining RMs are fully polymerized, fixing the orientation of the LCs in the off state [7]. For a PS-VA RM with a faster polymerization speed, it is essential to ensure high reliability as well. Reliability results of our latest LC mixtures with fast polymerizable RM are illustrated in comparison to standard PS-VA LC mixture in figure 2.

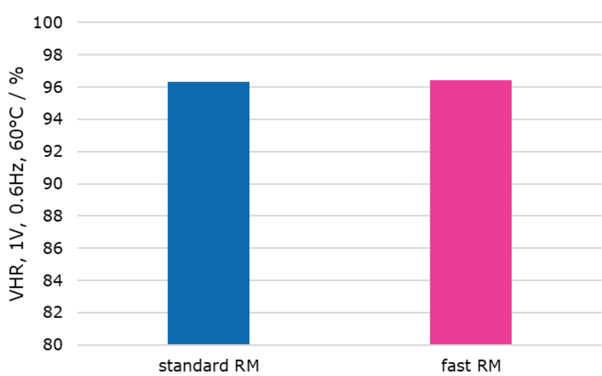

Figure 2. Comparable reliability parameter VHR of a standard (in mass production) PS-VA mixture vs. fast polymerizable PS-VA mixture.

All key parameters are satisfied with the new fast polymerizable RM and the designed PS-VA LC mixture is ready for mass production. We also measured the polymerization speed of the RM in a PS-VA test display, which was the primary motivation for this development. As shown in figure 3, the polymerization speed has improved by 55% compared to the RM currently used for mass production of PS-VA TV displays.

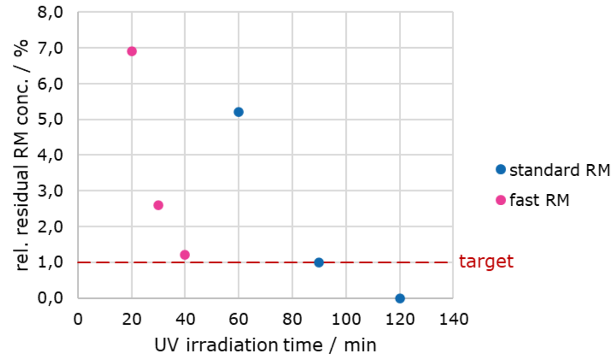

Figure 3. Significantly improved UV2-polymerization speed of fast polymerizable PS-VA mixture vs. standard PS-VA mixture; target relative RM concentration is about 1%.

3. SA-VA – PS-VA with additional energy saving potential and more sustainable production

SA-VA represents an advanced development of PS-VA, featuring a significant distinction. In addition to the PS-VA liquid crystal (LC) mixture, the SA-VA mixture incorporates self-aligning additives that ensure the vertical orientation of the LC molecules on the substrates. As a result, there is no need for additional orientation layers in the display, which directly reduces energy consumption during the manufacturing process by eliminating an entire production step. Traditional PS-VA displays require an orientation layer made of polyimide, which necessitates the use of polyimide solutions containing large amounts of solvents and high backing temperatures of about 230°C for stable layer formation [8]. This requirement is no longer applicable with SA-VA technology, as you can see in figure 4.

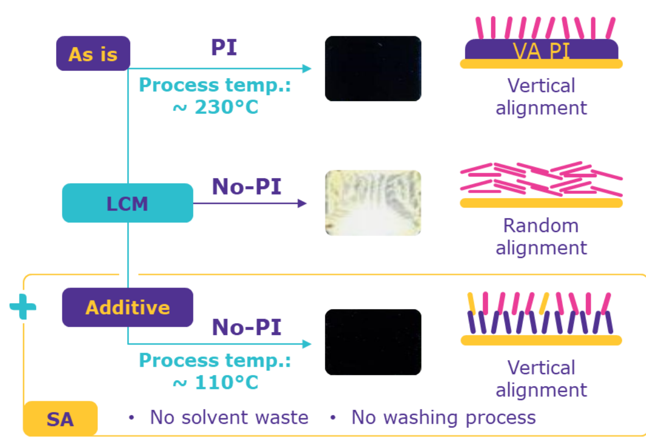

Figure 4. above: VA alignment with PI alignment layer (standard process); middle: no alignment due to missing alignment layer; below: Self VA alignment without alignment layer in case of SA-VA.

The self-aligned nature of SA-VA technology enables energy savings and reduces the use of chemicals in production.

Moreover, it allows for the potential use of more temperature-sensitive display materials, as the high backing temperatures of the substrates are not necessary. For instance, temperature-sensitive dye-containing color filters could be employed, which may further enhance the transmittance of an LCD compared to traditional pigment-based color filters [9], see figure 5. If successfully implemented, this could lead to energy savings not only during the manufacturing process but also in the final device.

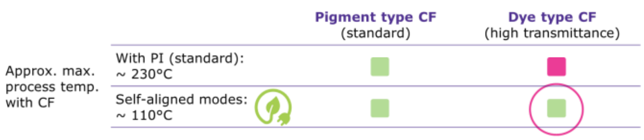

Figure 5. Proposal for further transmittance improvement using more temperature sensitive dye color filters in case of SA-VA (red symbol: not usable; green symbol: usable).

The SA-VA LCD technology is already in mass production for IT devices and is currently under development for TV application.

4. C-PS-VA – PS-VA with higher transmittance

C-PS-VA is the latest advancement in the series of PS-VA-related LCD technologies. The primary goal is to achieve higher transmittance than that offered by PS-VA. This increased transmittance directly translates into energy savings. With higher LCD transmittance, it is possible to either reduce the number of LEDs in the backlight system or decrease the power required for LED operation. This principle is already recognized as a viable method for energy savings in applications such as television sets.

C-PS-VA liquid crystal (LC) mixtures incorporate chiral dopants in addition to the classical PS-VA LC mixture components. By optimizing pixel design and LC properties, C-PS-VA can achieve a 15% higher transmittance in high-resolution-displays compared to PS-VA [10]. The effects of C-PS-VA on pixel transmittance are illustrated in figure 6.

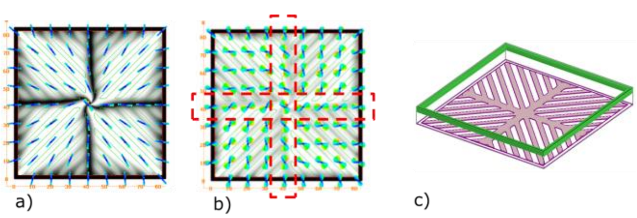

Figure 6. C-PS-VA working principle vs. PS-VA. a) Typical brightness of a PS-VA 4-domain pixel, including disclination lines at the edges of the domains. b) Improved, more homogeneous brightness of a 4-domain C-PS-VA pixel. c) Pixel electrode structure.

The inclusion of chiral dopants alters the properties of the LC mixture and its switching behavior, resulting in a 20% longer switching off speed. While this is a drawback of the technology, it can be addressed through further development of LC materials and optimization of the LC mixtures. The improvements achieved by such an optimized, fast switching LC mixture concept compared to a standard LC mixture concept can be seen in figure 7. The significant reduction of the switching off time by the LC mixture enables this LCD technology for mass production.

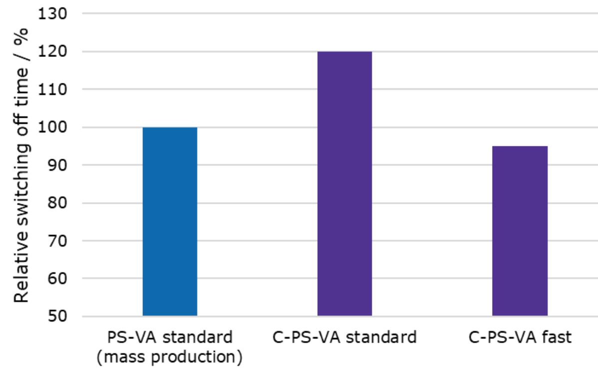

Figure 7. Switching speed improvements realized by optimized LC mixture and material design targeting for mass production.

Our latest LC mixtures for C-PS-VA effectively address the drawback of slower switching speeds compared to PS-VA.

5. UB-FFS and UBplus – high transmittance and low refresh rate (LRR) driving

UB-FFS and UBplus achieve up to 15% higher transmittance compared to FFS technology, thanks to the more efficient orientation of liquid crystals with negative dielectric permittivity in the electric field [11]. The resulting improved transmittance can be seen in figure 8.

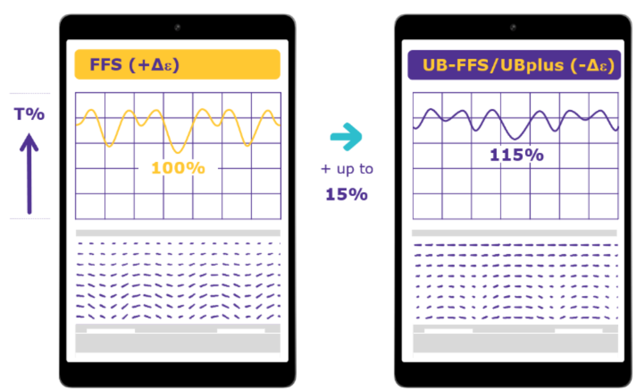

Figure 8. Orientation of LC molecules in electric field and resulting transmittance profile above electrodes of FFS vs. UB-FFS LCD technology.

This increased transmittance can be leveraged for energy savings or enhanced brightness in LCDs. A higher brightness level is particularly beneficial for improving the ambient contrast of LCDs, as the ambient contrast ratio provides a more realistic representation of contrast under typical lighting conditions compared to just the dark state contrast ratio. The energy-saving benefits can lead to various improvements depending on the application. For mobile devices such as smartphones, tablets, and laptops, the higher transmittance allows for reduced backlight power, which can extend battery life and enhance user comfort. In television applications, the increased transmittance of UBplus LCDs can be directly utilized for power savings, contributing to better energy labels and a reduced CO_2 footprint due to lower energy consumption. The impact on CO_2 emissions for television applications is illustrated in figure 9.

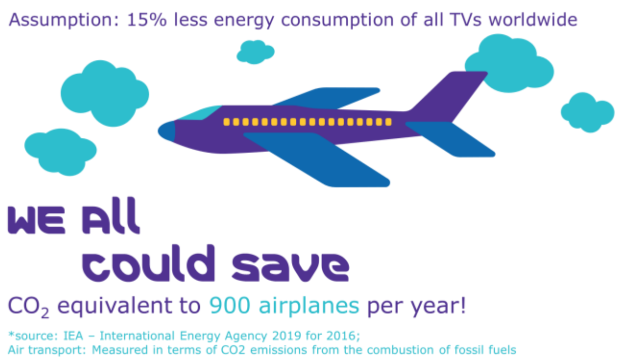

Figure 9. Illustration of CO_2 emissions savings in case all LCD TV sets worldwide could be operated with 15% less power, e.g. due to a higher transmittance of the LCD.

Additionally, the increase in transmittance offered by UB-FFS, combined with an optimized LC mixture, results in excellent flicker performance. Flicker refers to the fluctuation of transmittance over time, which can be quite disruptive for consumers if it is pronounced. This phenomenon is influenced by voltage holding ratio (VHR) and the flexoelectric effect, both of which must be optimized through careful design of LC molecules and mixtures. Currently, there is no definitive guideline for creating LC mixtures that minimize the flexoelectric effect, necessitating long-term experience, a diverse portfolio of LC molecules, and expertise in flicker measurement to achieve optimal results as shown in figure 10.

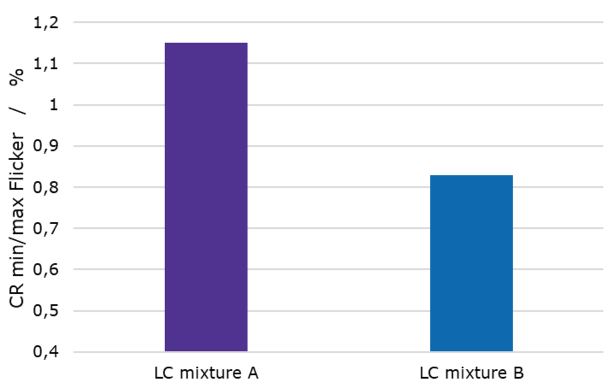

Figure 10. Improved flicker by UB-FFS LC mixture design targeting for ultra-low refresh rates for energy saving.

6. Summary and Outlook

Over the years and decades, many LCD technologies have been developed, primarily driven by the need for improved display performance and picture quality. This includes demands for higher display resolutions, which require greater transmittance, and higher ambient contrast ratios that necessitate increased brightness. The advancement of High Dynamic Range (HDR) technology has also contributed to the push for higher display brightness. While these factors remain important and ongoing efforts continue to optimize various display parameters, there has been a noticeable shift towards more sustainable and energy-efficient devices.

Merck KGaA, Darmstadt, Germany, has played a significant role in the development of such sustainable technologies. LCD innovations targeting a more sustainable production process like SA-VA and liquid crystal mixtures for PS-VA with faster polymerization speeds have been introduced to the market by display manufacturers, facilitated by our liquid crystal materials and mixtures. Additionally, technologies designed to reduce energy consumption in mobile, IT, and television devices, such as UB-FFS and UBplus, have been launched or are currently under development, like C-PS-VA or FSC LCD. These advancements will contribute to further reductions in CO_2 emissions and help lower energy costs for consumers. It is our aim to contribute to these future improvements with our continuous efforts in LC material development and LC mixture design.

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