Improving low temperature characteristics of new Ferroelectric Liquid Crystal for LCOS and SLM

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Abstract

Ferroelectric liquid crystals (FLCs) have two attractive characteristics: very fast switching speeds and stable alignment against electrical fringe fields from neighboring pixels. However, care needs to be taken because FLC panels can be prone to alignment defects caused by Chevron structures. In 2024, we succeeded in developing a new FLC for LCOS and SLM that has an improved temperature range of the SmC phase wider and is less occurrence of alignment defects. However, due to our focus on improving high-temperature characteristics, the switching speed was slower than conventional FLCs in the SmC phase at lower temperatures. In this report, we present our success in developing an FLC mixture that has improved low-temperature characteristics while maintaining the favorable properties developed previously.

1. Introduction

In recent years, AR glasses-type devices have been required to possess improved AR display characteristics, along with a size and design that is comparable to that of ordinary glasses. Thus, display devices for the AR device are required to be more compact, have higher resolution, and exhibit greater brightness (higher light efficiency) than ever before. For instance, regarding panel size and high resolution, if we assume that we want to achieve a display panel size of 0.15 inches and a resolution of FHD (1920 x 1080), the pixel pitch would need to be approximately 1.7um. Under this assumption, the pixel per inch (ppi) would be 14,000 or higher.

Ferroelectric liquid crystals (FLCs) possess characteristics such as spontaneous polarization (Ps) and very fast switching speeds compared to nematic liquid crystals, making them suitable for field sequential color (FSC) driving modes.

The FSC driving mode enables full color display at only one pixel without sub-pixels through time sequential driving, requiring only one-third of the pixel count compared to the color filter mode which has an RGB sub-pixel configuration. In other words, it is possible to make the pixel size three times larger than the RGB sub-pixel size of the color filter mode. This manufacturing advantage permits larger pixel sizes compared to the color filter mode. Additionally, FLCs are less affected by alignment changes due to the electrical fringe field effect from neighboring pixels compared to nematic liquid crystals, making it possible to realize a much narrower pixel gap, and thus increase the fill factor ratio[6,8]. Therefore, the combination FLC and FSC driving mode is suitable for realizing high resolution and high density small sized display panels.

2. Extant FLCs

In recent years there has been more demand for use of our FLC at higher temperatures and a desire to further expand the fields in which our FLC products are used. Moreover, from the standpoint of display quality and reliability, there is a need for further suppression of alignment defects[2,3]. Alignment defects are defects caused by changes or disruptions in the Chevron structure that occur due to surface stabilized FLC (SSFLC) mode[4]. This is due to a layer structure that exists in the SmC* phase of FLC. Controlling the occurrence of alignment defects is an important point in mastering the use of FLC. The major alignment defects in SSFLC include zigzag defects (ZZ), boatwake defects (BW), and quasi-bookshelf defects (QB).

Regarding zigzag defects (ZZ), their occurrence has been suppressed through our display process technology, including alignment control, and it is not currently a problem.

Boatwake defects (BW) occur due to higher voltage applications or other, larger, external factors that change the orientation state of the Chevron structure. They tend to occur from locations where changes in the Chevron structure are likely to occur within the panel, and the first change is considered to be a change in the Chevron angle.

Quasi bookshelf defects (QB) are defects that occur when the Chevron structure disappears and becomes a bookshelf structure as a layer in the SmA phase. Although the cause of their occurrence has not yet been fully clarified, we consider a bookshelf structure to exist at the point of the extension when the Chevron angle is changed. Therefore, we assume if the change in the Chevron structure is suppressed and the Chevron structure is kept in a state of no change, the occurrence of QB can also be suppressed, as with the suppression of BW.

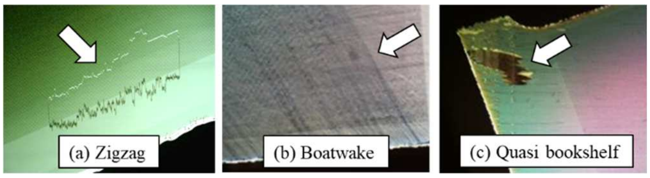

Figure 1. These photos, taken under a polarized light microscope, illustrate examples of the three major alignment defects in FLCOS.

As a temperature correction for contrast in SSFLC, we usually adjust the voltage application for FLC to align the liquid crystal director to the extinguished position at each temperature. This is because the cone angle changes with temperature. To suppress occurrence of BW, in some cases, the applied voltage at high temperatures is lowered below the voltage that we want to apply. In this case, the liquid crystal director is shifted in the extinguished position and contrast decreased. If an FLC with good BW resistance can be developed, it will be possible to improve the contrast at high temperatures. This is a major reason for us to develop new FLC.

In 2024, we succeeded in developing MX22483 as a new FLC mixture for LCOS and SLM that has an improved temperature range for the SmC phase wider and is less occurrence of alignment defects[6]. Table 1 shows the main target specifications for this project, which aims to expand the high temperature range of the SmC* phase and improve BW and QB resistance. It also includes information on MX20461 and MX22483. MX20461 is one of our mass produced FLCs and a reference material to compare with new FLC.

Table 1. The specifications for development new FLC mixture at room temperature.

Status/ FLC No.	Phase trans. C*-A [°C]	LTS [°C]	BW score	QB score	Switch-ing time [μsec]	Cone angle [°]
Target	>90	≤ -30	<Ref.	<Ref.	≤100	45±2
MX20461	88.3	<-30	0.50	0.07	213.2	40.3
MX22483	96.7	<-40	≒0	≒0	91.3	44.0

However, because of focusing on improving the high-temperature characteristics, the switching cone angle were narrower than conventional FLCs at lower temperature, in other words, larger voltage needs to be switching FLC molecules. And the switching speed were also slower than conventional FLCs at lower temperature. Figure 2 and Figure 3 shows the comparing conventional MX20461 with MX22483 about driving characteristic which applied ±1.8V at lower temperature. MX22483 is degraded driving characteristic under 10 °C. And under -5°C, MX22483 is not switched fully by applied ±1.8V.

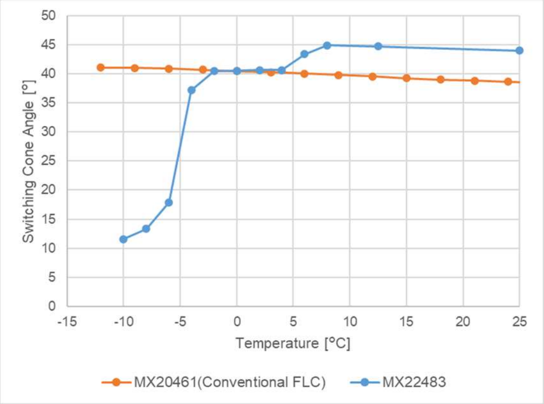

Figure 2. Graph comparing conventional MX20461 with MX22483 about switching cone angle which applied ±1.8V at lower temperature.

We assumed that the cause was that we increase the mixing ratio of rigid molecules to stabilize the layer structure and molecule alignment, as result, a viscosity of MX22483 increases. Table 2 shows the comparing conventional MX20461 with MX22483 about rotational viscosity at room temperature. The rotational viscosity value of MX22483 is proximately 9 times larger than conventional MX20461.

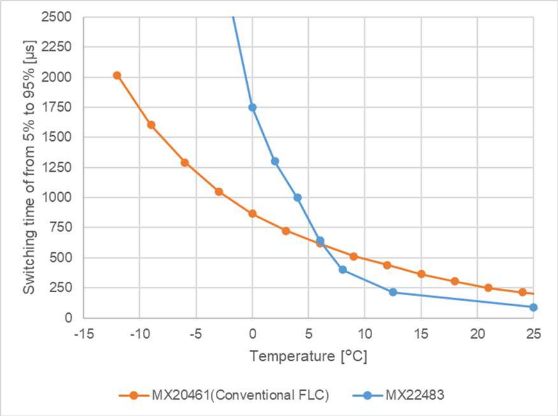

Figure 3. Graph comparing conventional MX20461 with MX22483 about switching time which applied ±1.8V at lower temperature.

Table 2. The specifications for development new FLC mixture at room temperature.

Status/ FLC No.	P$_S$_25 [nC/cm^2]	P$_S$_70 [nC/cm^2]	Rotational viscosity [mPa*s]	B$_3$_25	B$_3$_70
MX20461	35.1	30.1	88.7	0.75	2.02
MX22483	78.6	66.0	802.6	11.3	4.16

Thus, our major purpose is new advanced FLC mixture to improve driving characteristics until -10C as lower temperature, while maintaining the good characteristics of MX22483 developed previously.

3. Design new FLC

As an improvement guideline of mixture design, while maintaining the basic design policy established for MX22483, we hypothesized two approaches. One is to add fluorine group to FLC molecules to facilitate easier switching, another is to make the FLC molecules more rigid to ensure a stable layer structure. Since the addition of fluorine could potentially weaken alignment stability, so this design guideline aims to balance what may initially seem like contradictory principles: improving the stability of the layer structure and then making it easier to move with fluorine. We proceeded with the improving design of the FLC mixture based on this new guideline.

The basic design policy for MX22483 focuses on the substance parameters of spontaneous polarization PS (PS_25, PS_70, and PS changing rate (PSCR)) and twist elastic constants B3 (B3_25, B3_70, and B3 changing rate (B3CR)) were important. P$_S$_25 is the spontaneous polarization at 25°C, and P$_S$_70 is the spontaneous polarization at 70°C. P$_S$CR is the ratio of P$_S$_70/P$_S$_25 (P$_S$ retention rate). B$_3$_25 is the twist elastic constant at 25°C. Since we cannot directly measure the twist elastic constant, it was calculated from B$_3$_25 = γ_25/t_25 (the value obtained by dividing the viscosity at 25°C by the response rate at 25°C). B$_3$_70 is the twist elastic constant at 75°C, and it is calculated from B$_3$_70 = γ_70/t_70 (the value obtained by dividing the viscosity at 70°C by the response rate at 70°C). B$_3$CR is the ratio of B$_3$_70/B$_3$_25 (B3 retention rate). As BW are more likely to occur at high temperatures, it is important to focus not only on room temperature but also on the values at 70°C and the ratio of 25°C to 70°C.

4. Results

We developed new FLC mixture successfully with much trial and errors. We were able to obtain several FLC candidates that achieved our target specifications, and we report the best one.

The results of the new FLC development are shown below. Firstly, we show improving result of the new FLC mixture about lower temperature characteristics. Figure 4 and Figure 5 shows the comparing conventional MX20461 and MX22483 with new FLC of MX22674 about driving characteristic which applied ±1.8V at lower temperature. MX22674 keep switching fully by applied ±1.8V even under 10 °C as same as conventional MX20461. Regarding switching time of MX22674, we have results which is faster than one of MX20461 by applied ±1.8V at -10 °C.

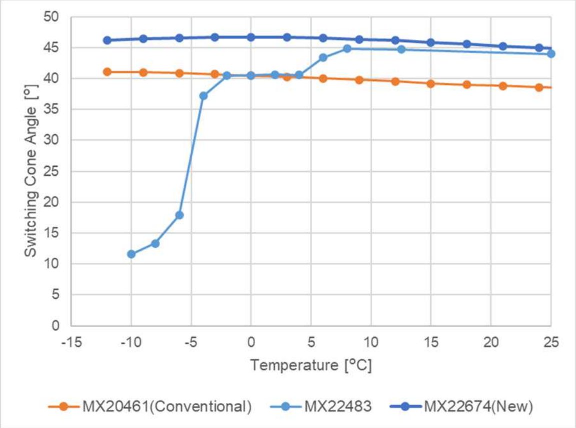

Figure 4. Graph comparing conventional MX20461 with MX22483 about switching cone angle which applied ±1.8V at lower temperature.

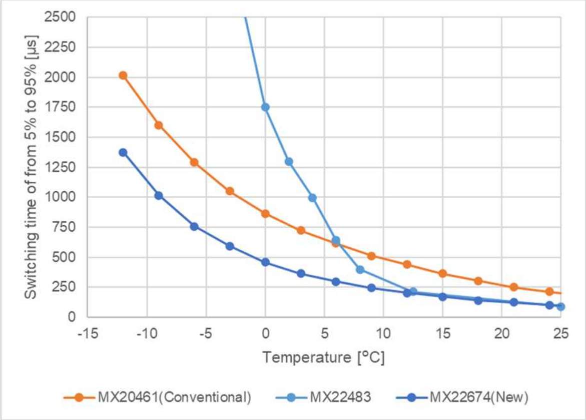

Figure 5. Graph comparing conventional MX20461 with MX22483 about switching time which applied ±1.8V at lower temperature.

Secondly, we show results of the new FLC mixture about alignment stability etc. and substance properties. (See Table 3 and Table 4). The SmC-A phase transition temperature of the New FLC exceeds 97°C, and it has excellent BW and QB resistance, as well as achieves the targets for other specifications. The result shows the new FLC of MX22674 is better than MX22483, excepting switching time at room temperature. We could reduce rotational viscosity value of MX22674 compared MX22483, however the value is larger than MX20461. That means rotation viscosity value reduce by addition of fluorine group, and to need both some rigidly and the viscosity to keep alignment stability.

Table 3. The specifications for development new FLC mixture at room temperature.

Status/ FLC No.	Phase trans. C*-A [°C]	LTS [°C]	BW score *1	QB score	Switch-ing time [· sec]	Cone angle [°]
Target	>90	≤ -30	<Ref.	<Ref.	≤100	45±2
MX20461	88.3	<-30	0.44	0.07	213.2	40.3
MX22483	96.7	<-40	0.17	≒0	91.3	44.0
MX22674	97.2	<-40	0.06	≒0	103.3	45.0

*1 The BW and QB scores are indices with 0 being the best. For BW, under the previous conditions, both MX22483 and MX22674 were 0, making it impossible to judge whether they were good or bad, so by addition test conditions on the high temperature side, we made it possible to compare them.

Table 4. The Ps, Rotational viscosity and B_3 values for development of new FLC mixtures.

Status/ FLC No.	Ps_25 [nC/cm^2]	Ps_70 [nC/cm^2]	Rotational viscosity [mPa*s]	B_3 _25	B_3 _70
MX20461	35.1	30.1	88.7	0.75	2.02
MX22483	78.6	66.0	802.6	11.3	4.16
MX22674	74.7	53.2	575.8	7.55	7.70

Thirdly, using an LCOS panel injected with New FLC, we investigated the voltage at which BW defects began to occur for each temperature. The results are shown in Figure 6 below. Compared to MX22483, the voltage at which BW occurs using this new FLC was higher across the higher temperature range. This means that it has improved BW resistance and we can apply higher voltages than with MX22483. The BW resistance has improved, so we can say that the alignment stability in higher temperature driving has improved beyond previous levels.

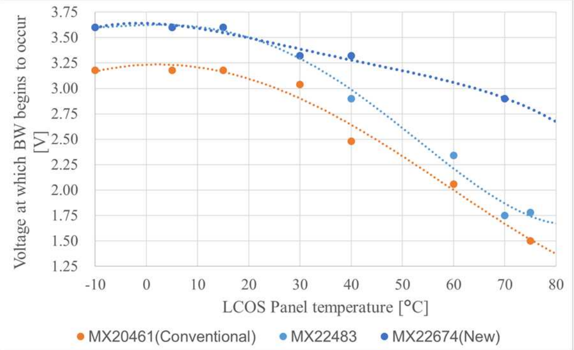

Figure 6. Graph comparing MX20461 and the New FLC in terms of voltage at which BW defect begins to occur vs LCOS panel temperature.

As the new FLC is now able to withstand higher voltages than MX22483, it has less axis deviation in the extinguished position, and we achieved higher contrast at high and low temperatures than before. Figure 7 shows the comparison result of the contrast temperature characteristics.

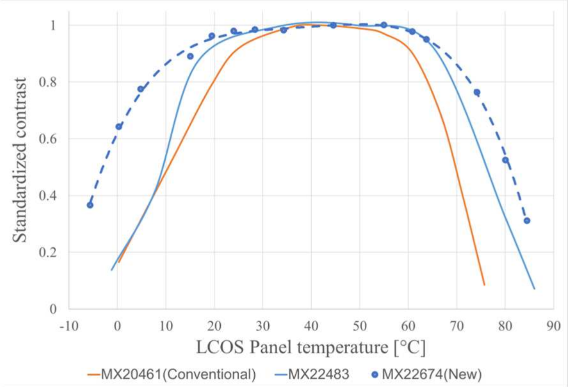

Figure 7. The comparison graph between MX20461, MX22483 and the New FLC for standardized contrast value vs LCOS panel temperature.

Figure 8 shows the graph of cone angle's temperature characteristics compared between MX20461, MX22483 and the new FLC. The new FLC also have characteristics of more wider cone angle than MX22483 even in high temperature ranges.

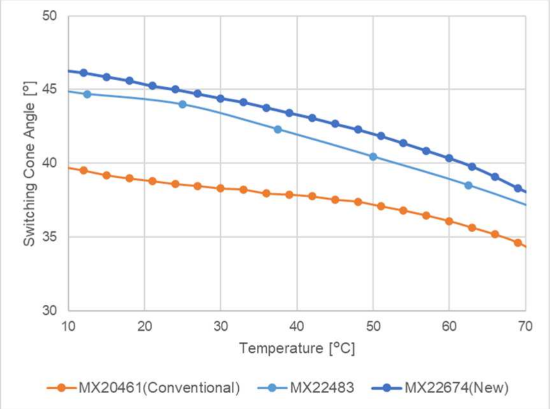

Figure 8. The graph of cone angle's temperature characteristics compared between MX20461, MX22483 and the new FLC.

Figure 9 shows the graph of Vth characteristics compared between MX20461, MX22483 and the new FLC by using 0.7 um cell gap glass-glass panel. The new FLC also have characteristics to be able to switch by applied lower voltage than MX22483. Being able to operate at low voltages allows the transistor withstand voltage to be reduced, which leads to smaller pixel size, and is an important factor in realizing small, high-definition panels.

5. Conclusion

We successfully developed an excellent advanced FLC mixture that achieved the target specifications. We have not only improved the low-temperature driving characteristics, but also increased the alignment stability at high temperatures. We were able to achieve a trade-off between ease of driving and alignment stability by balancing the overall mixture design. As a result of these improvements, it is now possible to switch the new FLC mixture with a lower driving voltage than before. We have created a well-balanced and excellent FLC mixture.

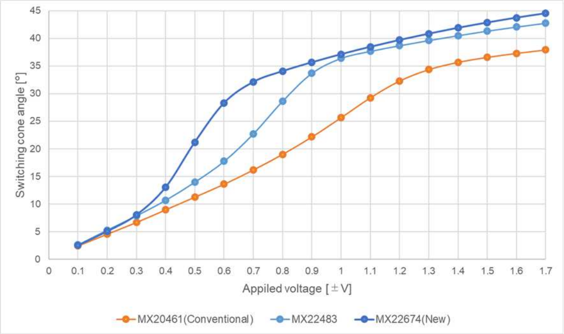

Figure 9. The graph of Vth characteristics compared between MX20461, MX22483 and the new FLC.

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