A New Dimming Technology and Applications Based on Dye-Doped Liquid Crystal

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Abstract
The newly developed dimming technology based on dye-doped liquid crystal boasts remarkable features such as flexible dimming capabilities, rapid response times, low haze levels, reduced thickness, and an enhanced yield rate. It has passed auto - grade tests and shows potential in transport and architecture.

Keywords
dye molecules, liquid crystal cell structure; dimming technology;

1. Introduction
With the development of the times, people's pursuit of the quality of life and their demand for intelligent control are increasing day by day. Therefore, the importance of dimming technology demonstrated in numerous fields has become increasingly conspicuous. Traditional dimming technologies (such as SPD, PDLC, EC etc.) often run into issues such as limited adjustment range, slow response time, and inadequate stability [1]. By virtue of its distinctive performance advantages, the dimming technology based on dye-doped liquid crystal has emerged as a heated topic in both research and application and it holds vast development potential. Compared to EC's chemical reaction-based dimming, dye-doped liquid crystal dimming offers superior response speed (millisecond level) and stability. Unlike SPD and PDLC, dye-doped liquid crystal dimming requires a low voltage drive of less than 20 V, which enhances its safety. Currently, the mainstream dimming technology of dye-doped liquid crystal enables the function of dimming by double liquid crystal cells[2]. However, it has problems such as high requirements for laminating and significant differences in thickness between its assembled products and the original glass. This paper studies a new dimming technology based on dye-doped liquid crystal, which can effectively improve the above problems and has advantages such as a variable dimming range, reduced product thickness, and improved laminating yield.

2. Technical principle
Dimming technology based on dye-doped liquid crystal refers to the selective absorption or transmission of specific wavelengths of light by dichroic dye molecules, which change their orientation in conjunction with the changes in liquid crystal molecules due to the dichroic properties of the dyes. The current mainstream dye-doped liquid crystal dimming technology enables the function of dimming by stacking two liquid crystal cells with perpendicular alignments (Figure 1). The new dimming technology shares the same principle as the mainstream dye-doped liquid crystal dimming technology (Figure 2), and uses a polarizer (POL) to replace one of the liquid crystal cells. By aligning the absorption axis of the POL perpendicular to the alignment of the liquid crystal cell, it leverages Malus' law. The POL can be affixed to the surface of the cell, simplifying the device structure to one single liquid crystal cell, thereby reducing product thickness (Figure 3). The new device structure has higher strength and better toughness, it is more conducive to manual operation by staff in the lamination process, and can effectively prevent the occurrence of cell damage issues in the course of lamination process.

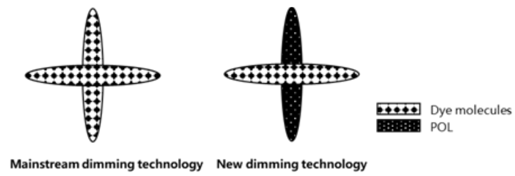

Figure 1. **T**echnical principle comparison

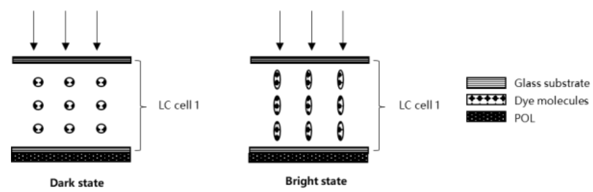

Figure 2. Structure and bright/dark state morphology

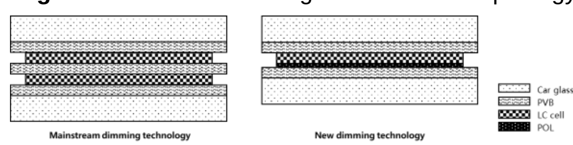

Figure 3. Product thickness comparison

3. Technical features
Compared to traditional dye-doped liquid crystal dimming technology, the new dimming technology exhibits superior performance and characteristics. The following presents a detailed exposition of its features.

3.1 Variable dimming range

In traditional dye-doped liquid crystal dimming technology, the adjustment of the dimming range needs to be achieved by changing the parameters of the cell gap. With the new technology, it becomes feasible to render the dimming range variable by altering the polarizer (POL), even when the cell gap remains constant. The following table presents a comparison of the optical specifications between the two technologies. As shown in the table, the new technology can achieve extremely low transmittance under the premise of constant contrast. This characteristic makes the dimming devices applying this technology better aligned with in-vehicle privacy protection needs.

Spec	Mainstream dimming technology	New dimming technology		
Structure	Gap-A	Gap-A+ pol-1	Gap-A+ pol-2	Gap-B+ pol-1
Bright state	2.8%	1.6%	0.98%	0.7%
Dark state	33%	20%	11%	21%
Contrast	11.7	12.5	11	30

Figure 4 Specification comparison

3.2 Haze

The new technology has inherited the characteristic advantage of low haze from the traditional dual liquid crystal cell dimming

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technology. Currently, the haze of the product combination is less than 3 in the dark state and less than 1 in the bright state.

3.3 Response Time (RT) and Voltage-Transmittance (VT)

The new technology features a fast response time, quickly responding to input electrical signals. Currently, the response time of the B mm cell thickness + polarizer combination is in the millisecond range at room temperature. The response time speeds up as the temperature rises and slows down as the temperature drops. The response time curve is shown in Figure 5. The transmittance change curve of the new technology at different voltages is shown in Figure 6.

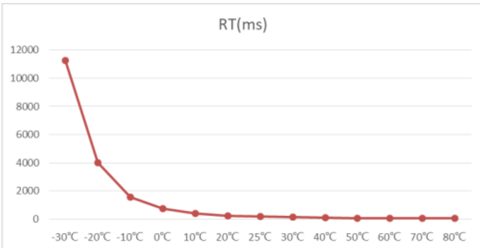

Figure 5 Response Time (RT)

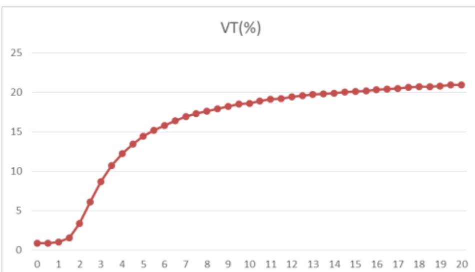

Figure 6 Voltage-Transmittance (VT)

3.4 Viewing Angle

The absorption axis of the polarizer is in a fixed direction. The rubbing direction of the liquid crystal cell has only two directions, one is vertically upward perpendicular to the absorption axis and the other is vertically downward perpendicular to the absorption axis. For these two alignment combinations, the front and rear viewing angles are both in the dark state, while there are differences between bright and dark states in the up and down viewing angles. Compared with the four viewing angle situations of the mainstream technologies, it is reduced to two types (Figure 7).

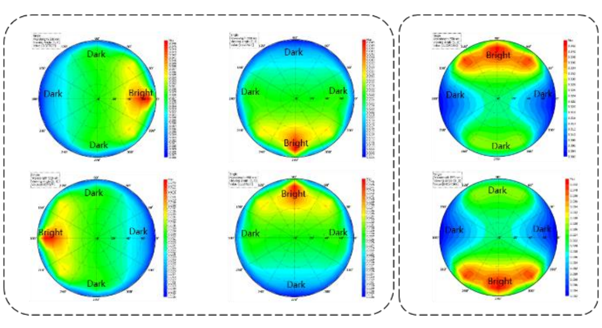

Figure 7 Simulation diagram of special viewing angle characteristics

In summary, the new dye-doped liquid crystal dimming technology features characteristics such as lower dark-state transmittance, higher contrast, extremely low haze, faster response time and better viewing angles.

4. Passed rigorous automotive-grade tests

Dimming devices with three structures, namely cell gap of A mm + pol-1, cell gap of A mm + pol-2, and cell gap of B mm + pol-1, were selected. They were laminated to LGU samples for testing. All three types of samples passed the automotive-grade reliability tests. The experimental conditions are shown in the following table.

Numb	Lab Project	Test Duration	Completion Status
1	High-temperature storage	2000h	OK
2	Low-temperature resistance	1000h	OK
3	High-temperature and high-humidity storage	1000h	OK
4	Thermal shock	1000h	OK
5	Radiation resistance	100h	OK
6	Baking	5h	OK
7	Response time	2h	OK
8	Environmental alternating test	240h	OK
9	Corrosion resistance	960h	OK
10	Heat resistance (boiling)	3h	OK
11	Power cycling	360h	OK
12	Xenon lamp 3929	1500h	OK
13	Haze	3h	OK
14	Insulation resistance	8h	OK
15	Electric breakdown	3h	OK
16	Extreme high temperature.	6h	OK
17	Electrode pull-out force	3h	OK
18	Impact resistance	5h	OK
19	Vibration durability	100h	OK

Figure 8 Test list

5. Conclusion

This paper studies a new dimming technology based on dye-doped liquid crystal, and is intended to resolve the issues present in traditional dimming technologies for instance, the narrow dimming range when the cell gap is fixed, the relatively elevated transmittance in the dark state, and the fact that the product thickness surpasses that of the counterparts in the industry. Through the utilization of the structure with the polarizer (POL) affixed to a single liquid crystal cell, the new technology encompasses numerous advantages. The device applying the technology achieved a variable dimming range, millisecond-level response speed, low haze and reduced thickness. And it can provide an enhanced yield rate during the manufacturing process. In terms of reliability, this technology has undergone and passed rigorous automotive-grade tests, thereby demonstrating its high application reliability and stability. It holds significant potential in transparent display integrated systems, and light dimming scenes in the fields of transportation and architecture, thus presenting broad prospects for future development and utilization within these domains.

6. References

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