# Single-panel simulation on liquid crystal on silicon

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## Abstract

*In this study, we report simulation results of single-panel LCOS (liquid crystal on silicon). Reflective LCOS microdisplays are widely used in various projection and near-eye application. For one panel system, liquid crystal response time is an important variable. The panel must switch fast enough to support the display of Field color sequential with high field rates. In order to have fast response and good contrast, a vertical alignment (VA) cell was used in this study.*

*With suitable selection on LC parameters like temperature, viscosity, elastic constant and birefringence, it is possible to get response time of around 2ms from a 2.0 um-thick vertical alignment cell. This result also indicates an ease of production control on 2.0 um cells than 1.0 um cells.*

## 1. Objectives and Background

Reflective LCOS microdisplays are widely used in various projections and near-eye application. There are many advantages from one-panel systems. The main benefit is cost reduction brought by reducing the number of optical components. In addition, it can eliminate the complicated production procedure for three panel system alignment and adjustments.

In most cases, the misconvergence caused by poor optical alignment results in poor image quality. To tackle this problem longer tact time is needed. It is more demanding when the resolution comes to1080p On the other hand, there is no alignment problem in one panel microdisplays.

In order to drive the panel with fast field rate without image flicker and color break, the liquid crystal must switch fast enough. The switch time also need to satisfy the color sequential scheme that maximize use of light. The target value is less than 2.2ms.

To reduce the response time a thinner cell gap is normally proposed[1, 2]. But it will be challenging to fabricate thin cells and yield loss is expected. So the balance between manufacturability and cell thickness has to be considered in new cell design.

In a field sequential color projection system, red, green, blue colors or information are generated in continuous time secession on the same panel. This results in lower lumen throughput. So compare with three-panel system, we need keep reasonable brightness levels by having an optimized reflectance from single panel cells and considering suitable etendue for whole project system. A separate study on the influence on etendue will be made in the future.

In this study, simulation will be made on VA cells seeking a response time of about 2.2 ms.

## 2. Results

Figure 1 shows a R-V curve single panel simulation. For 450nm, 550nm, 650nm wavelength, respectively. It is a 2 $\mu$m thick vertical alignment cell. The threshold voltage is 2.1 volts.

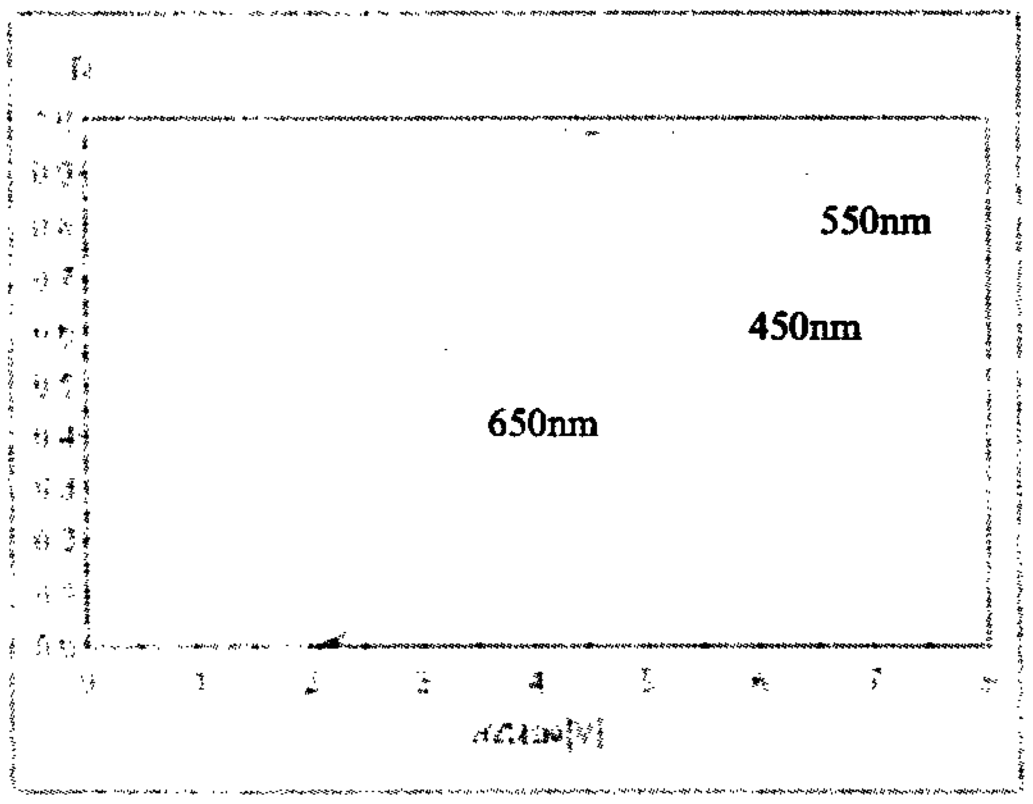

**Figure 1:Simulation on R-V curve of a VAN 2$\mu$m cell**

The reflectance can reach >95% for 550nm and 450nm light. The 650nm light reflectance is 75%. The driving voltage to max brightness level for Green and Blue is lower than 5V. These values seem to be reasonable for LC driving voltage range. This drive range is similar to that of J. E. Anderson[2]. However, it is noted that current LC cell has a thickness of 2.0 um, rather than 1.3 um. This indicates a much higher manufacturing yield since cell thickness uniformity is more easy to control at 2.0 um than at 1.3 um. In addition, LC cells can be made with conventional spacer bead without special spacer posts by photolithography.

In optical engine system, the operational temperature of LCOS panel was generally located at about 40~60 degree C[3, 4]. In our recent study, the relationship between temperature and response time was investigated on a 3$\mu$m VA liquid crystal cell[4]. In that study we found the rise time decreased by a factor of 1.58 at 45 degree C and a factor of 2.00 at 55 degree C compared with that at 20 degree C, shown in Figure 2. The main factor that result in shorter rise time is the rotational viscosity decrease. Figure 2 also shows linearity between rise time and temperature in the range of 25 degree C to 55 degree C. So put this relationship into simulation., we found the temperature-dependent properties can be optimized. Figure3 show the response time at 20, 45 and 55 degree C, respectively.

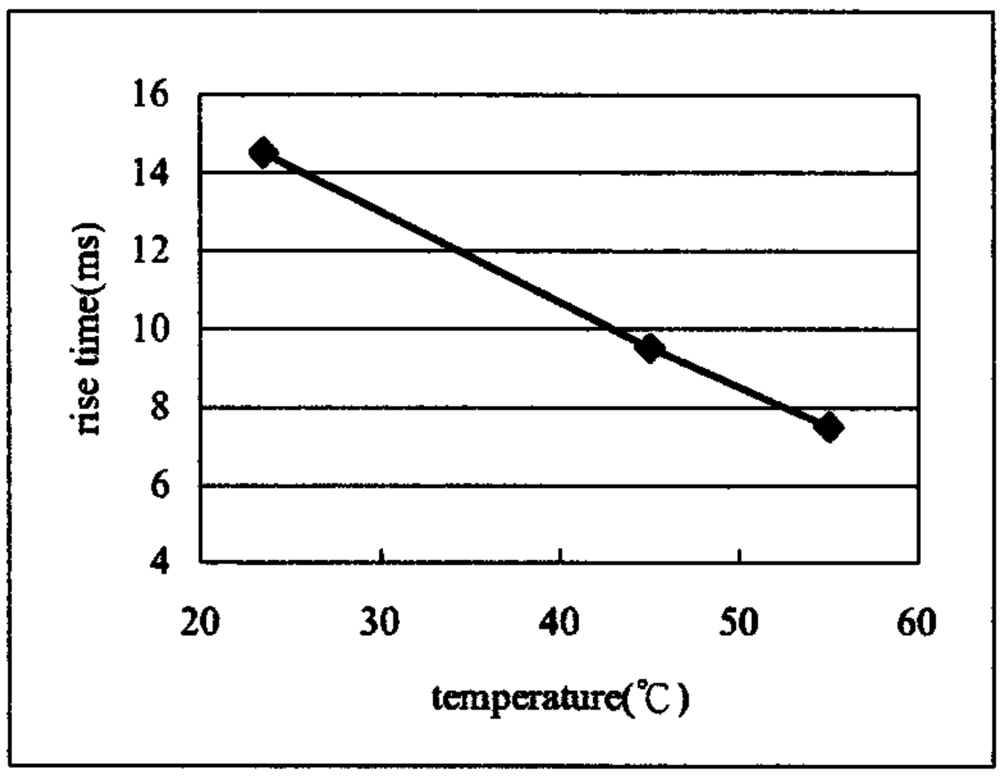

**Figure 2: Response time of a 3$\mu$m VA liquid crystal cell at different temperature.**

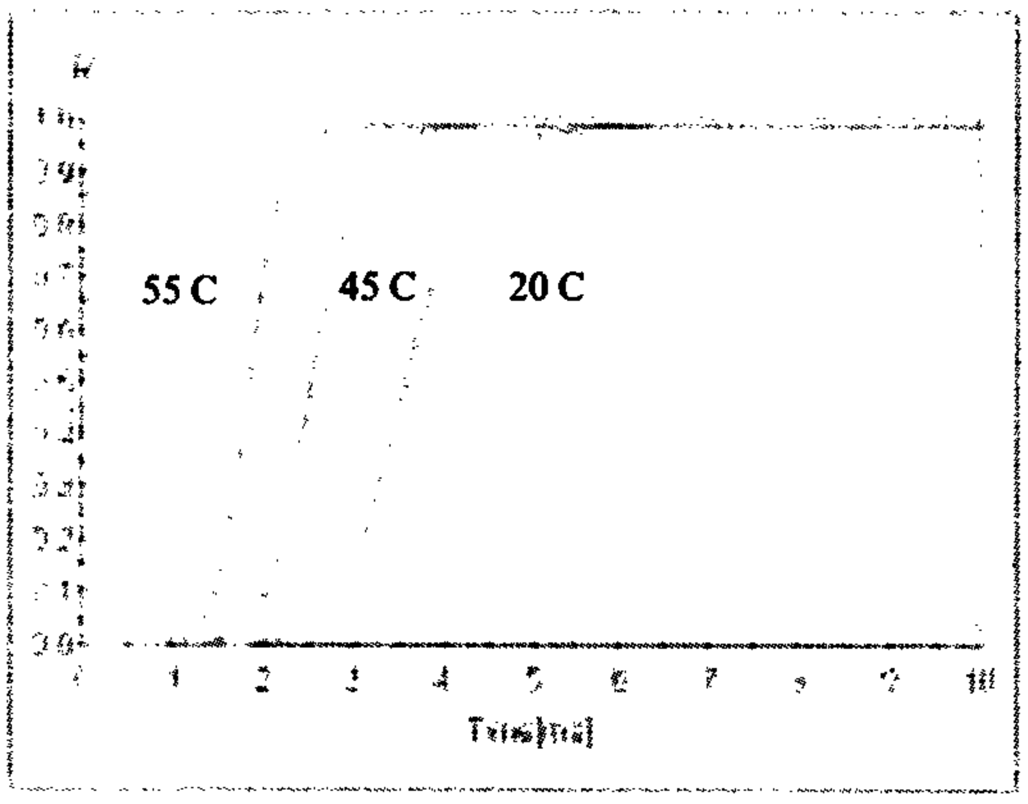

**Figure3: Response time with different rotational viscosity at different temperature.**

The results of the simulation were checked 550nm light and 89 degree pretilt angle. With the drive voltage of 4.8 volt, the liquid crystal switch speed can reach 2.2ms when LCOS panel reached 55 degree C.

To keep suitable applied voltage and reasonable brightness for different wavelength, different pretilt angle was simulated. Table 1 shows the simulation results of pretilt angle

Table 1 is obtained from the simulation of 89, 88, 85 degree pretilt angle with 2$\mu$m thick vertical alignment cell operated at 55 degree C. All response times are checked at 550 nm.

The response time of all cells with pretilt in the range of 85 to 89 degree are all less than 2.2 ms. The contrast of cells with pretilt 85 degree and 89 degree were further analyzed, shown in Table 2. It is clear that contrast of 89 degree pretilt is several times better than that of 85 degree. As a result, 85 degree pretilt gives a better response time but poor contrast. While 89 degree pretilt gives better contrast but has risk of LC molecule reverse tilt. To consider the contrast and avoid reverse tilt domain effect, we propose an optimized pretilt at 88 degree.

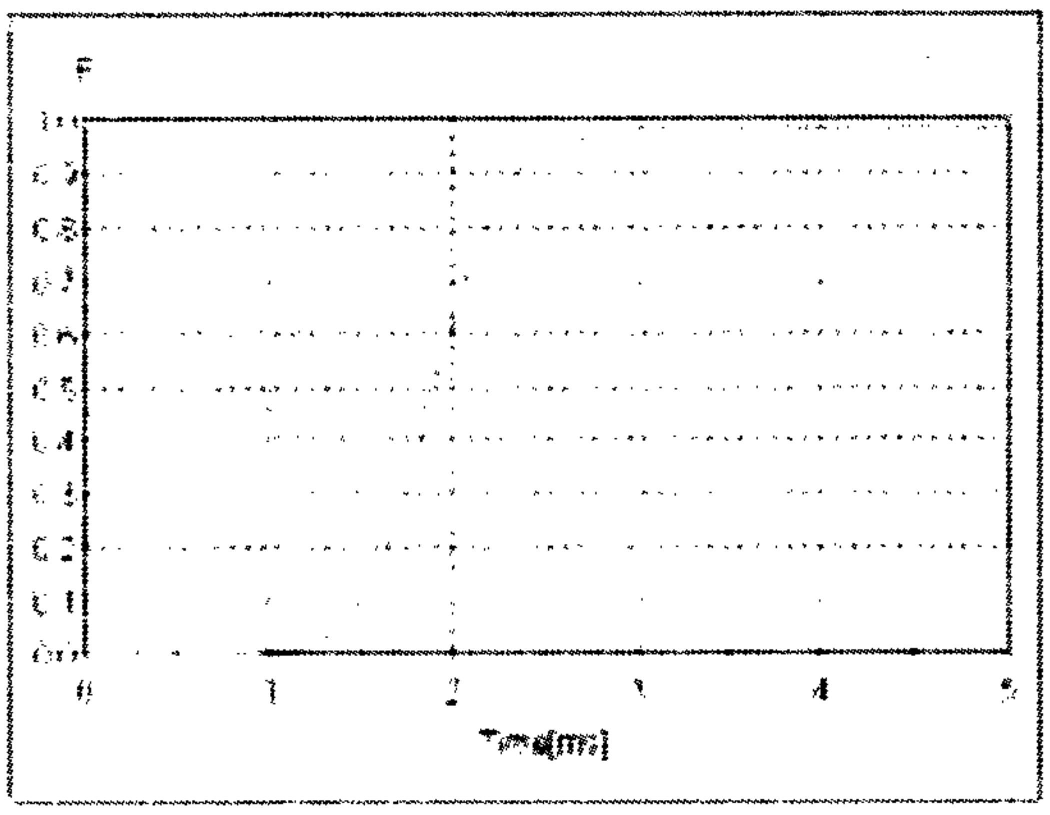

**Figure 4:Simulation results of rise time for pretilt angle 89 degree on 2$\mu$m VA cell**

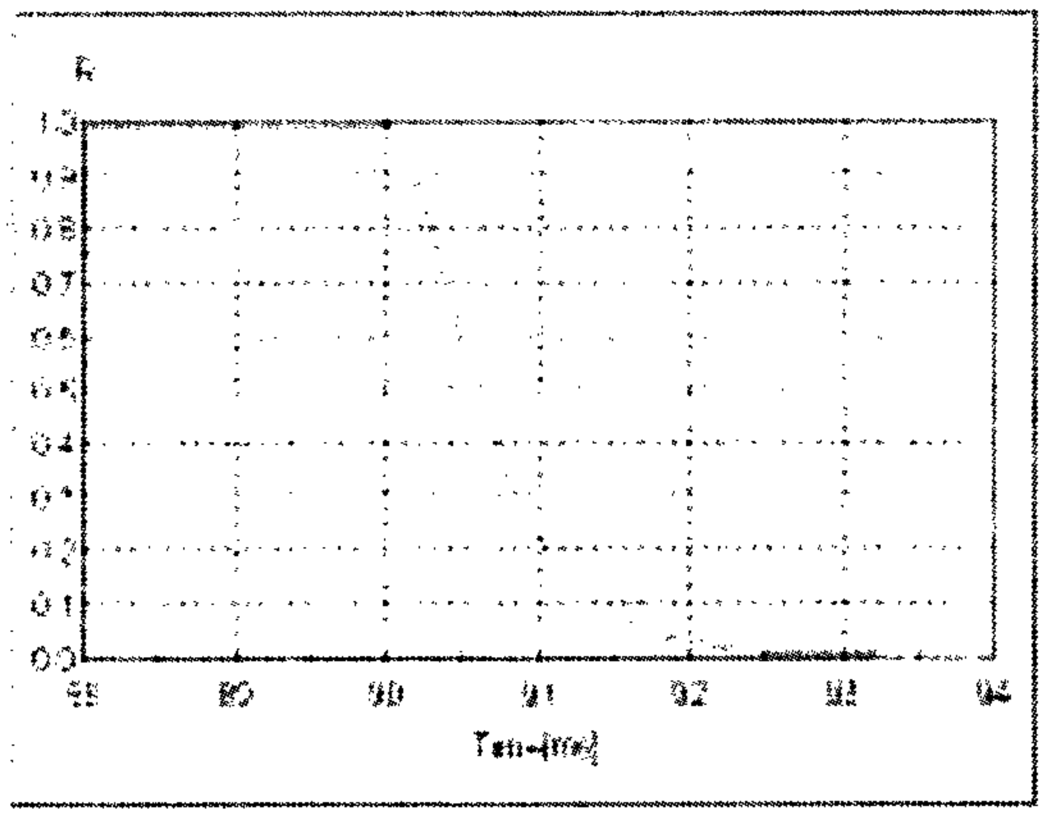

**Figure 5:Simulation results of fall time for pretilt angle 89 degree on 2$\mu$m VA cell**

Figure 4 shows the rise time of pretilt angle 89 degree; the rise time and fall time are defined as intensity change between 10 % and 90%. The rise and fall time are 0.821 and 1.203 ms as show in figure 5.and figure 6.

The rise time decrease to 0.701ms when the pretilt angle kept at 85 degree, as show in Figure 6. And the fall time increase to 1.334ms as show in figure 7.

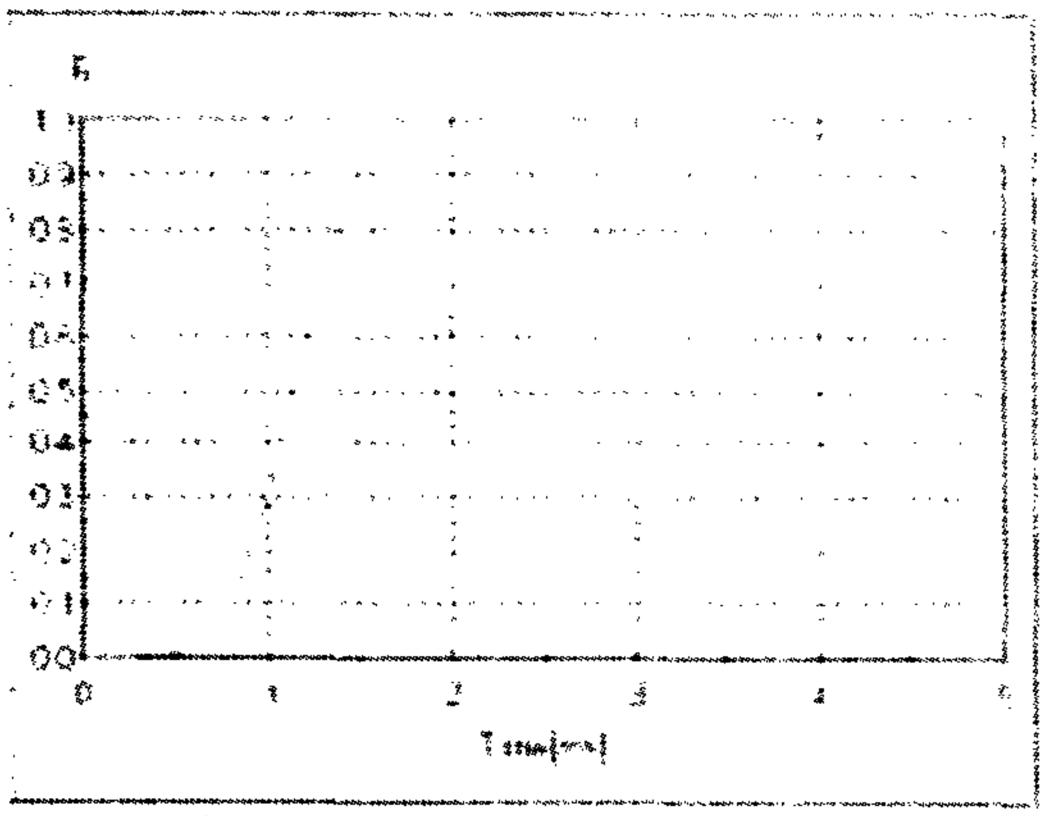

**Figure 6:Simulation results of rise time for pretilt angle 85 degree on 2 $\mu$m VA cell**

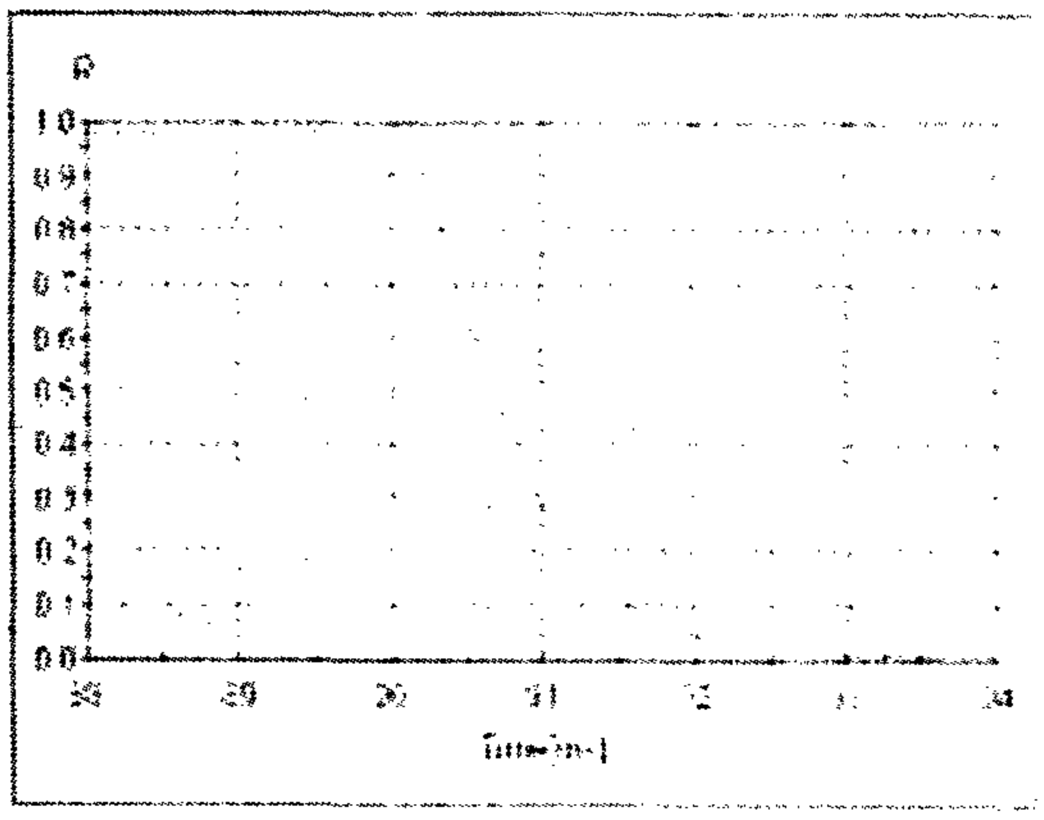

**Figure 7:Simulation results of fall time for pretilt angle 85 degree on 2 $\mu$m VA cell**

In general, smaller pretilt angle would lead to a faster fall time but slower rise time. It is also noted that the delay time is longer for low pretilt angle cells.

The influence of wavelength on the response time was further checked and shown in Table 3. In this case, we assumed 88 degree pretilt angle. Since this an optimized pretilt for reflectance, contrast, and response time

For 450nm, 550nm wavelength light at 88 degree pretilt angle, the response time can reach 1.964 and 2.017ms at 55℃. Although the response time of 650nm was slower, rise time can be improved with higher drive voltage for red. This indicates that a cell of fast response in full visible wavelength is feasible when proper drive voltages are applied.

## 3. Conclusions

In this study, the liquid crystal mode is normally black, vertical alignment, driven in less than 5V. It has fast response and suitable reflectance. The cell has a 2 $\mu$m thickness. It will be easier for production compared with other thinner cell gap design[5].

## 4. Acknowledgement

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## 5. References

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**Table 1: response time at different pretilt angle simulated at 55 degree C**

| Pretilt angle | Rise time (ms) | Fall time (ms) | Tr+Tf (ms) |
|---|---|---|---|
| 89 degree | 0.821 | 1.203 | 2.024 |
| 88 degree | 0.788 | 1.229 | 2.017 |
| 85 degree | 0.701 | 1.334 | 2.035 |

**Table 2: Contrast ratio at different pretilt angle.**

| Pretilt angle<br>Contrast ratio | 89 degree | 85 degree |
|---|---|---|
| 450nm | 2400 | 470 |
| 550nm | 4100 | 780 |
| 650nm | 4200 | 810 |

**Table 3: response time with different wavelength and temperature at 88 pretilt angles.**

| Time (ms)<br>Wavelength | | Rise time | Fall time | Tr+Tf |
|---|---|---|---|---|
| 20 degree | 450nm | 1.331 | 2.579 | 3.910 |
| | 550nm | 1.556 | 2.475 | 4.031 |
| | 650nm | 2.281 | 2.597 | 4.878 |
| 45 degree | 450nm | 0.843 | 1.634 | 2.477 |
| | 550nm | 0.994 | 1.569 | 2.563 |
| | 650nm | 1.426 | 1.633 | 3.059 |
| 55 degree | 450nm | 0.670 | 1.294 | 1.964 |
| | 550nm | 0.788 | 1.229 | 2.017 |
| | 650nm | 1.133 | 1.281 | 2.414 |