Novel CMOS-backplane Technologies for Fine Pixel Pitch and High Image Quality of LCOS Microdisplay

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ABSTRACT

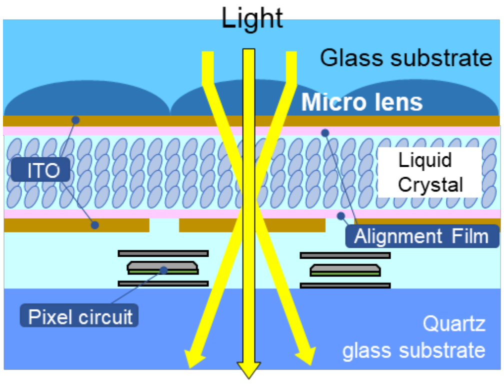
In this paper, the latest micordisplay development statuses, including the 0.90-inch native 8K panel with 2.6 x 2.6 um pixel, and our unique CMOS LSI-based backplane dedicated technology used in high-performance LCOS devices are introduced.

1. Introduction

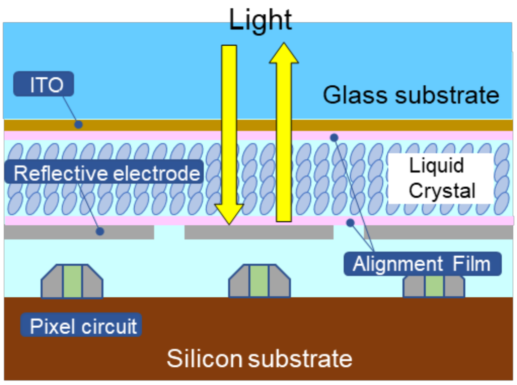
Transmissive LCD, reflective LCOS, and reflective MEMS micromirror are the main types of devices used in projectors [1-4]. The transmissive 3-LCDs and single reflective MEMS systems are used for high brightness business projectors due to their simple and efficient optical system. Since the reflective LCOS uses CMOS devices as the backplane, it has been mainly used for professional simulators and home cinema projectors where high image quality is required. In recent years, small LCOS devices have also been used in portable projectors and AR glass [5]. In addition to projectors, the use of SLM phase modulators for HUDs and laser processing is also increasing [6-8].

We have developed both transmissive and reflective liquid crystal microdisplays. Fig.1 shows the device structures and their features. The characteristics of the transmissive type are a highly efficient simple optical system, and low-cost high temperature polysilicon TFT based backplane on glass substrate. In the transmissive type, microlens technology is used to achieve high transmittance to compensate for the reduced aperture ratio caused by TFT backplane. Reflective LCOS, on the other hand, achieves high aperture ratio without the use of microlenses, thus providing high-contrast and high-definition image quality without the screen door effect. In addition, for high-definition projector applications, high uniformity and high brightness are also required.

In this paper, we report on the latest LCOS device development and its unique technologies using dedicated CMOS LSI process to enhance the image quality.



(a) Transmissive type



(b) Reflective type

Fig.1 Structures of Liquid Crystal Microdisplay

2. The LCOS device features with fine pixel pitch

We have developed LCOS devices for 3-panel system in home cinema use and for single-panel system in portable projector use showing in Fig.2&Table.1 The single-panel LCOS uses a color sequential drive technique. For the 3-panel system, we developed 0.90-inch LCOS with 2.6μm pixel pitch and native 8K (7680 x 4320) high-density pixels. For this backplane, we prioritized miniaturization by adopting a low-voltage digital drive system and an advanced CMOS process.

On the other hand, for the single-panel system, we developed the 0.37-inch FHD (1920 x 1080 pixels) LCOS with 4.25μm pixel pitch. This backplane uses an analog LC drive method with high voltage drive to achieve color sequential drive and portable application, resulting in improved liquid crystal response time and reduced power consumption. This makes pixel pitch miniaturization difficult, but we have achieved this by taking advantage of the low duty cycle of analog drive and adopting a layout that reduces the transistor size by more than 20% avoiding the HCI (Hot Carrier Injection) and BTI (Bias Temperature Instability) degradation compared to normal design rules. In other words, we have backplane technology for both digital and analog LC drive methods, and both methods achieve a fine pixel pitch. In addition to this, we use inorganic alignment films and VA mode liquid crystals to achieve high photostability and high contrast.

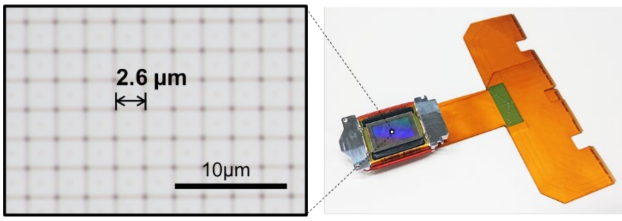


Fig.2 Native 8K LCOS with 2.6μm pixel pitch

Table.1 Specifications of LCOS devices

	Digital Drive 3-LCOS	Analog Drive 1-LCOS
Pixel Size	2.6um□	4.25um□
Resolution vs Panel Size	Native 8K: 0.90 inch (7680 x 4320)	FHD: 0.37 inch (1920 x 1080)
Pixel Driving Voltage	Low (3.3V)	High (6.0V)
Gray Scale	12bit	8bit
Frame Rate	120Hz	360Hz Color Sequential Available
Power Consumption	High	Low
Device Option For circuit	HV/LV CMOS	HV/LV CMOS Pixel Capacitor
Summary of Advantages	High Definition(4K/8K) High Image Quality	Minimize Form Factor Battery-powered

3. CMOS-backplane technologies for fine pixel pitch and high image quality

3.1 Reflective electrode structure with high definition and high reflectivity

In conventional LCOS devices for projectors, highly reflective pixel electrodes are realized by combining Al metal, which has high reflectivity in the visible light range, and dielectric multilayers to increase the reflectivity. However, as the pixel pitch becomes finer, the decrease in aperture ratio due to slits between pixels and the decrease in reflectivity due to diffraction phenomena become major issues. As the light sources of recent projectors have become laser-based, the reduction in reflectance due to diffraction loss can no longer be ignored.

To solve the problem of reduced aperture ratio, we have developed a process to reduce the space between pixels from 0.22μm, which is the limit in conventional CMOS processes, to 0.16μm by optimizing the Al reflective electrode structure and lithography process. In addition, a low refractive index film was inserted into the high dielectric film of the dielectric multilayer located in the inter-pixel space as shown in Fig.3(a)(b) to solve the reflectivity reduction due to diffraction loss. Fig.3(c)(d) shows the simulation result by RCWA method, and it is confirmed that the intensity of transmitted and diffracted light in the inter-pixel space is reduced. Fig.4 shows the pixel pitch dependence of the reflectance when this dielectric slit structure is used.

For example, based on a pixel pitch of 4.0um and an inter-pixel space of 0.22um with conventional structure, the reflectivity decreases to 95% when the pixel pitch is reduced to 2.6um. Therefore, by applying this new low dielectric constant slit structure to the native 8K LCOS, the reflectivity is first recovered to 97%. Furthermore, by reducing the inter-pixel space to 0.16um, we were able to increase the reflectance to 106%, which is higher than the original reflectance.

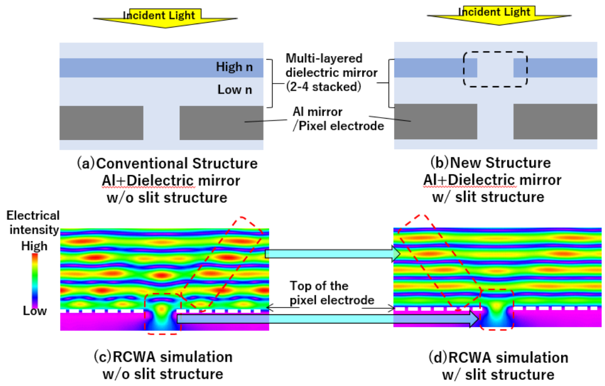


Fig.3 Pixel electrode structure and RCWA simulation results

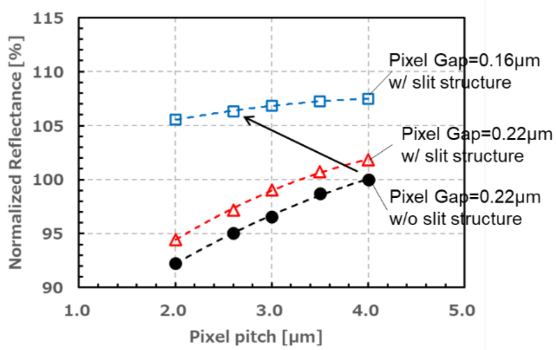
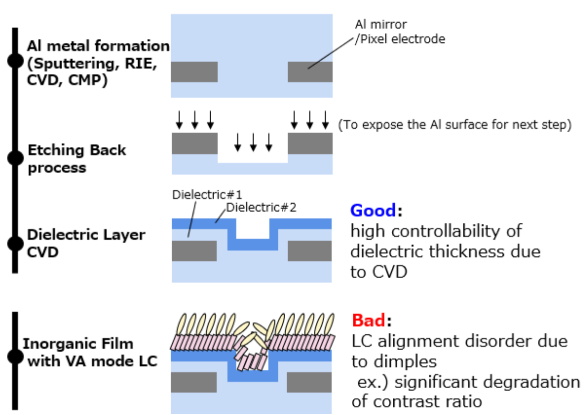


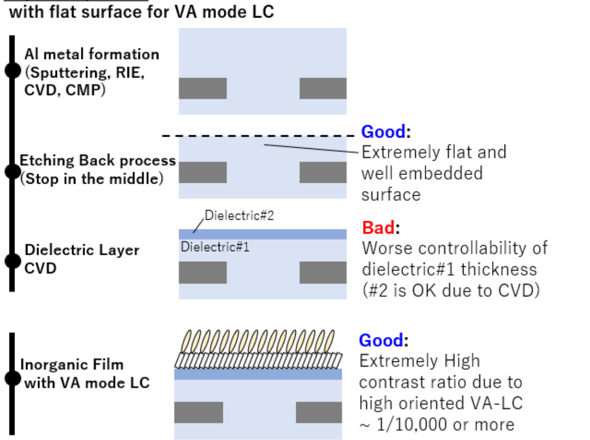
Fig.4 Simulation result of reflectance w/ or w/o low dielectric slit structure for λ=520-580nm

3-2. High contrast flat reflective electrode with inter-pixel gap planarization technology

When dielectric multilayers are used to increase the reflectivity, there is a problem that the reflectivity decrease due to variations in the thickness of the dielectric multilayers becomes very large. For this reason, as shown in Fig.5(a), it is common to use an etching back process in which the oxide film on the electrode is once removed. However, since the gap between pixels is not flat, even though it covers a very small area, the orientation of the liquid crystal is deviated, resulting in a very small amount of light leakage. Since the contrast performance of high-definition projectors can reach as high as 1,000,000:1, this slight degradation can result in a significant loss of contrast. Then, the next idea is to stop the etching back process of the oxide film on the electrode in the middle and combine it with the CMP process to ensure the flatness of the pixel gaps, as shown in Fig.5(b). In this case, we had to accept the trade-off of a larger variation in the thickness of the first dielectric layer as the contrast improved.



(a) Conventional process flow



(b) Improved process flow

Fig.5 Reflective pixel electrode process flow with dielectric multilayer

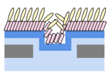
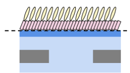
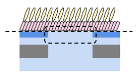
	Conventional Process	Improved Process	This Work
Mirror Structure			
Feature process	Etching back process	Etching back process + CMP	(same as improved process)
Reflectance [a.u.]	100	Deteriorating → 90	Improving → 105
Contrast Ratio	2,000:1	Improving → 10,000:1	Improving → 10,000:1

Fig.6 Pixel electrode structures and specifications

In the present structure, in which a low-k slit is inserted into the dielectric multilayer, the process has been further optimized to resolve this trade-off, and high contrast and high reflectivity have been achieved at the same time (Fig.6).

3-3. Cell gap with excellent uniformity by CMP optimization

The last technology to improve image quality is high uniformity cell gap control technology. In the controlling of the cell gap shape, while the liquid crystal injection process is important, the biggest factor is the uniformity of the surface profile of the glass or backplane that forms the cell. The glass has only a uniform structure on the surface, such as an ITO layer, so it has a highly uniform surface profile. On the other hand, CMOS backplanes have non-uniformly distributed patterns on each of the CMOS and wiring metal layers. Therefore, the surface uniformity of the backplane is usually not good, either at the global level of the entire wafer or at the local level of a single chip (even if the level is not a problem in LSI). In especially, since the level required for cell gap control of LCOS is on the order of 1μm, intra-chip flatness control of 100nm or less is required to realize high performance LCOS.

Fig.7 shows an example of cell gap uniformity control by optimizing the CMP process. As shown in the figure, in LCOS backplanes, there is often an extremely large difference in layout density between areas where pixel circuits are packed to the limit, such as within effective pixels, and the surrounding areas. The auto-dummy, which is optimized for standard processes, prevents CMP process-induced defects and provides sufficient chip flatness for LSIs that require only normal electrical operation. However, as mentioned earlier, it is insufficient to provide the level of control required for high-performance LCOS. To solve this problem, we improved the flatness and symmetry of the surface profile by stacking analysis of the layout density distribution and appropriately modifying the layout distribution of each layer as shown in the figure. As a result, after the improvement, the maximum value of the cell gap is suppressed, and the maximum value is controlled at the center of the cell.

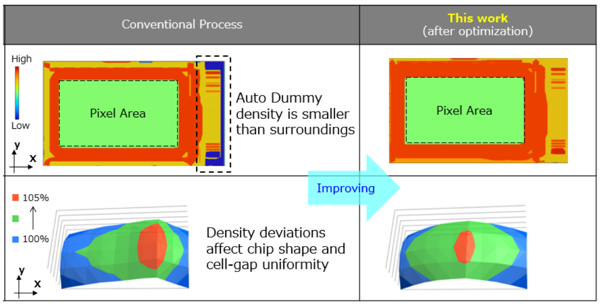


Fig.7 CMP process optimization for cell gap uniformity control

4. Inorganic alignment film and VA-mode liquid crystal for high photostability

Liquid crystal devices are generally weak when exposed to short wavelength light or high brightness light for a long period of time. If the light resistance is insufficient, the liquid crystal material will decompose, causing image degradation and resulting in defects. Ionic impurities generated from the decomposed liquid crystal material not only reduce the endurance voltage, but also accelerate the reaction between the liquid crystal and the radicals. Finally, the liquid crystal phase disappears or gasifies, and bubbles are generated.

We have improved the photostability characteristics of LCOS by optimizing the liquid crystal compounds and inorganic alignment film, and as a result, we have realized a 10klm projector using a 0.74-inch 4K panel. Since the newly developed 0.90-inch native 8K LCOS device is expected to achieve exceeding 15klm brightness, new applications such as large conference rooms are expected to be expanded in addition to theater applications.

5. Conclusion

We introduced the digital drive 3-panel LCOS with 2.6μm pitch native 8K pixels, the analog drive single-panel LCOS with 4.25μm pitch FHD pixels, and the unique CMOS backplane technology applying for these devices to enhance image quality. We will continue to develop smaller and higher performance LCOS to further expand the projector market.

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