World's Largest E Ink Spectra 6 Display for Signage with IGZO-TFT Backplane

Fumiyuki Kobayashi*, Kohhei Tanaka*, Kaoru Yamamoto*, Masayoshi Takai*, Shunsuke Kobayashi**, Shogo Murashige**, Takehiro Kitaura**, Wataru Nakamura*, San-Long Lin***

***Sharp Corporation, Panel Semicon Laboratories, Nara, Japan**

****Sharp Corporation, Panel Semicon Laboratories, Mie, Japan**

*****E Ink Holdings, Hsinchu, Taiwan**

Abstract

Large driving voltages limits the size of electrophoretic displays, when used with amorphous silicon TFTs for high frequency page updates. To increase the display size Sharp have used IGZO TFTs with high mobility and stability to make an A1 paper-size display with E Ink Spectra™ 6 electrophoretic foils for excellent color. This is the largest Spectra 6 display that has ever been made.

Author Keywords

Electrophoretic display; Full color; Spectra 6; IGZO; TFT; Stability to high applied voltage; ePoster

1. Introduction

So far high-resolution Signage displays that can be used for reading timetables and text are dominated by LCDs. These consume relatively large amounts of power because they must be driven continuously and need strong Back Lights, especially in bright sunlight. With rising awareness of the dangers of global warming due to rising CO_2 levels in the atmosphere and strongly increasing energy prices there is an increasing interest in finding low energy alternatives, but these must also have good optical performance.

Electrophoretic Displays (EPDs) have long been known as extremely low power Black and White displays which have mainly been used for eReaders and Electronic Shelf Labels. The low power needed for driving EPDs is due to driving voltages only being needed when displays are being updated, the image is retained by particles in the display holding their position when there is no applied external electrical field. In addition, EPDs do not need Front Lights in bright ambient conditions, like sunlight, and only need weak Front lighting in the dark. As noted above, in contrast LCDs must be continuously driven and need very strong Backlights, particularly in bright conditions.

EPDs also have the advantage of paper-like appearance and extremely wide viewing angles. However, Black and White displays have limited attraction for Large Signage, particularly when the alternative is LCDs with vivid colors. In order to be able to service the Signage market E Ink has recently developed full color Spectra 6 EPDs that display vivid colors while retaining the advantages of low power driving, paper-like appearance and wide viewing angle.

Large Active-Matrix LCDs are commonplace, from outdoor Signage through transport timetables to domestic LC-TVs, which can be more than 100" in diagonal. The optical transmission of LCDs depends on the orientation of Liquid Crystal molecules and it only takes a relatively low voltage of about +/-6V to rotate the LC molecules very quickly. The low voltage means that TFT panels for LCDs can have small pixel storage capacitors and TFTs, which minimizes the capacitive load on Gate and Source lines, making large LCD panels relatively easy to drive. The result is that large 100" diagonal LCDs can be driven, even by low mobility amorphous silicon TFTs.

In contrast Electrophoretic Displays (EPDs) change image due to movement of charged colored particles in a viscous fluid, with the driving force coming from an applied electrical field controlled by the TFT backplane. The color of pixels depends on the color of the charged particles at the top of the pixel. The force needed to move particles in an electrical field is significantly larger than the force needed to rotate a long molecule in LCDs, so EPDs need larger driving voltages and update times are significantly longer than for LCDS. The higher voltages needed for movement of the charged particles means larger storage capacitors are needed in the pixels, which in turn requires larger TFTs to charge them. The larger capacitance of TFTs and storage capacitors increases the RC loading on Gate and Source lines. Below we will explain how this makes the size of EPDs that can be driven by TFTs smaller than the maximum size of LCDs.

The aim of this work was to make the first large display panel with Spectra 6 EPDs. In addition to the heavy capacitive loading of TFT panels for driving EPDs the aim of this work was to enable advanced driving for improved page transitions. This needs 120 Hz driving, which is about twice as high as typical 65 Hz driving for EPDs. The higher frame rate decreases the time available for charging pixels, which further reduces the size of panel that can be driven.

ISO 216 sets a series of paper sizes, with the "A" series being the most commonly used in retail and transport applications. Sharp's aim for Spectra 6 displays is to make thin, light signs that can be drop-in replacements for paper signs. For this work we have targeted making an A1-sized Spectra 6 display module that will be the largest Spectra 6 module that has ever been made. In order to be able to support this size with high frame rate for advanced driving we have used Sharp's IGZO TFTs with higher mobility and good electrical stability.

We have demonstrated the world's largest A1 signage display using Spectra 6, based on the A-size paper format without tiling.

2. Spectra 6 Electrophoretic Displays

Spectra 6 is fabricated by an additive roll-to-roll process on a layer of microcup array. The key step in the process is to fill the electrophoretic ink into the microcup array and then apply a durable sealant layer on top [1, 2]. The electrophoretic ink contains blue and red positively charged particles and yellow and white negatively charged particles, with the red and yellow particles being larger than the white and blue particles. The red, yellow, and white particles are reflective and the blue particle semi-transparent. Small particles move slower than large particles in a viscous liquid and E Ink gives further control on speed by applying different amounts of charge to the particle shells.

The particles are suspended in a viscous ink that allows movement of the charged particles in an applied electrical field, but hold the

ISSN 0097-996X/25/5602-1275-$1.00 © 2025

particles in position when no external electrical field is applied. This is key to low power performance of EPDs because when the particles are in the correct position no further driving voltage is needed. The observed color of a pixel depends on the uppermost particles.

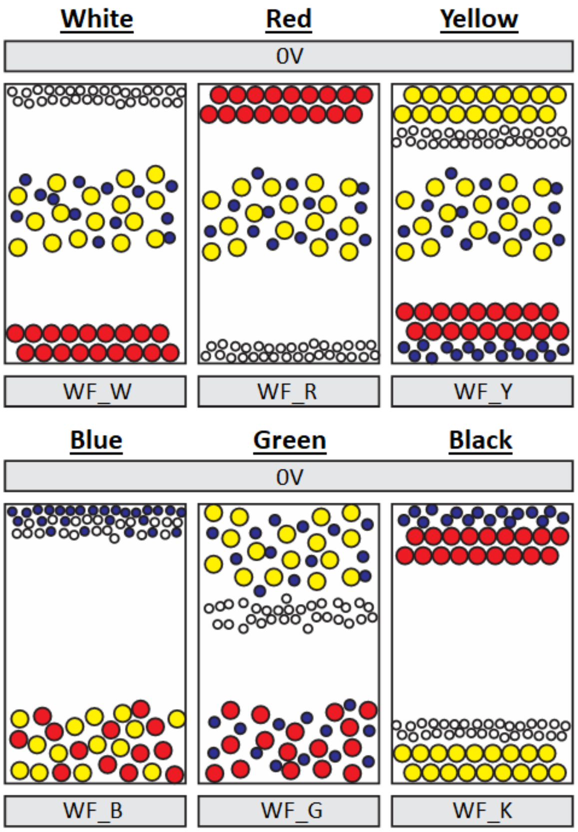


Fig. 1 Pigment arrangement in Microcups to display the colors shown at the top of Microcups.

The combination of different particle sizes and electrical charges makes the particles move at different speeds. The yellow and white particles are both negatively charged so they will both move towards the top surface when a negative voltage is applied to the bottom electrode. However, the white particle has been engineered to travel faster so they will separate from the yellow particles and arrive at the top electrode first. If the driving voltage is stopped at this point the pixel will appear white. If negative volts are kept on the bottom electrode the yellow particles will also reach the top surface and mix with the white particles. Applying a positive voltage to the bottom electrode will then move the faster white particles towards the bottom surface, leavfiging yellow particles closer to the top surface. If the electrical field is removed at this point the pixel will appear yellow.

Using different particle speed in different sequences of applied electrical fields E Ink has developed waveforms in the range +/-15V and frame rates as low as 50 Hz that control the vertical position of the pigments, as shown in Fig. 1. These six colors are the major palette colors of Spectra 6. Other colors are created by dithering, as shown in Fig. 2.

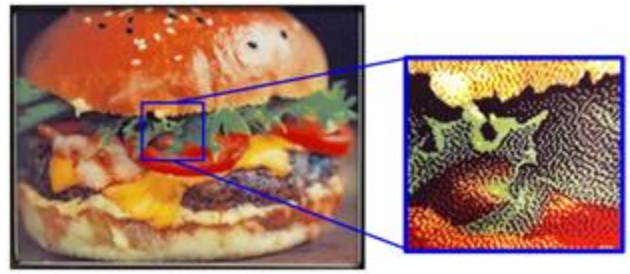


Fig. 2 Photographs of image on Spectra 6 EPD. The photograph on the right is zoomed-in to show how we use dithering of six basic colors to show a full range of colors.

We have to use a series of voltage pulses of different magnitude and polarity to drive the pigments to the correct vertical sequence for showing the six colors, so the image transition takes more than ten seconds and is “flashy as we transition through different colors. For instance, in the example above we explain how it is necessary to drive the pixel first to white, then mixed white / yellow, before finally arriving at yellow. Other pixels showing other colors will also tend to transition through other colors before reaching their final color. E Ink are now developing advanced driving of Spectra 6 that will reduce the update time and how many intermediate colors are needed before arriving at the final voltage. Standard Spectra 6 driving only needs +/-15V driving with 50 Hz frame rate, but advanced driving needs significantly higher driving voltages of +/-24V and 120 Hz. Frame rate.

3. TFT Backplane for Spectra 6 EPDs with Advanced driving

The aim of Sharp is to develop the most attractive Spectra 6 displays possible as replacements for paper signs. his includes having the shortest and most attractive page transitions as possible. For this reason Sharp decided to make A1 size displays with high voltage and high frame rate driving. In addition to high voltage and fast charging the TFTs must also have good electrical stability and minimal off-current leakage,

Moreover, high-quality Spectra^{TM}6 images necessitate high storage capacitance and high pixels per inch (PPI), which require the support of high-mobility TFTs. In large-screen signage applications, the RC load of the bus line is substantial, making the on-state capability of the TFT critical for adequately writing sufficient drive voltage to the pixels.

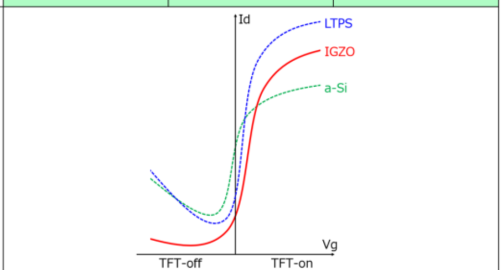
Candidates for the TFTs used in the backplane include a-Si TFT, LTPS TFT, and IGZO TFT, as summarized in Table 1. Currently, a-Si TFTs are widely employed in e-Paper applications. However, under high voltage conditions, a-Si TFTs demonstrate instability and exhibit significantly high off-leakage, along with insufficient mobility, rendering them unsuitable for charging high capacitance at high frame rates, such as required for Spectra 6.

In contrast, while LTPS TFTs exhibit higher mobility than a-Si TFTs and IGZO TFTs, they also suffer from off-leakage issues similar to those of a-Si TFTs, as silicon-based devices cannot achieve the low off-leakage characteristics of IGZO TFTs. For these reasons, IGZO TFTs are considered the optimal device for Spectra 6. Numerous reports have documented that IGZO TFTs exhibit high mobility, high on-current, and very low off-leakage current.

Furthermore, the feasibility of high-voltage operation has been confirmed through our high-voltage testing, which included high-voltage AC, Negative Bias Temperature Stress (NBTS), Positive Bias Temperature Stress (PBTS), and Vds stress. These tests demonstrated that the devices are sufficiently stable to withstand all forms of stress [3].

The cross-sectional structure of the IGZO TFT used in the developed A1 panel is illustrated in Fig. 3(a), while the planar layout is presented in Fig. 3(b), and the Id-Vg curve is shown in Fig. 3(c). The IGZO TFT is a bottom-gate, coplanar (BCE) type.

Table 1. Id-Vg characteristics of a-Si TFT, LTPS TFT, and IGZO TFT at high voltage application.

Application	a-Si TFT Mobility ~ 0.5 cm²/Vs	LTPS TFT Mobility ~ 80 cm²/Vs	IGZO TFT Mobility ~ >10 cm²/Vs
Vg-Id			
High voltage (+/-30V)	Difficult	Difficult	Good
High frequency	Difficult	Excellent	Good

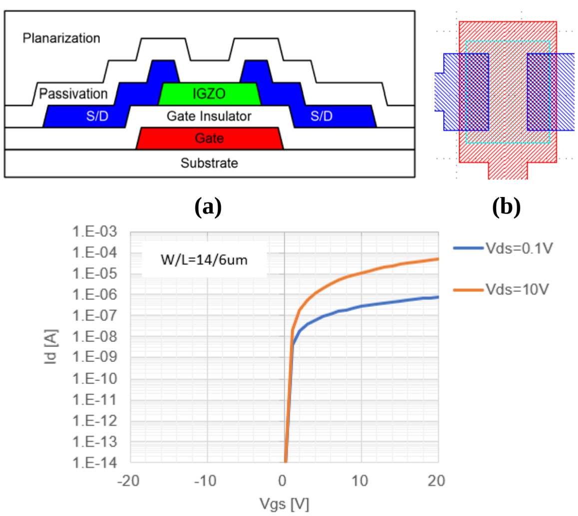


Figure 3. (a) Cross-sectional structure, (b) Planar layout, and (c) Id-Vg curve of the IGZO TFT used in this study.

Circuit simulation of driving:
As shown in Figure 4(a), the A1-sized module features two gate driver ICs positioned on both the left and right sides, with eight source driver ICs arranged along one side of the panel's long edge. This configuration is advantageous for driving high R/C loads quickly, particularly in large-screen applications such as signage. Additionally, locations for simulations are indicated by numbers 1 to 10. The equivalent circuit and basic parameters of the pixels are illustrated in Figure 4(b).

For a horizontal scan time (1H) of 18.2 μs, the pixel charging time (Ton) is set to 15 μs. The data voltage is defined as VDH/VDL = 24V/-24V, and the gate voltage is set to VGH/VGL = 35V/-35V.The SPICE model incorporates the latest characteristics of IGZO TFTs.

Figure 5 presents the charging simulation results at 50 Hz for the Spectra 6 system, conducted using SmartSpice™ from Silvaco Inc.. As the high gate voltage (VGH) is decreased, it becomes evident that insufficient charging occurs relative to the input data voltage. The target charging rate is set at 92%, and at VGH = 35V, the charging rate exceeds 99%, thereby comfortably meeting the target.

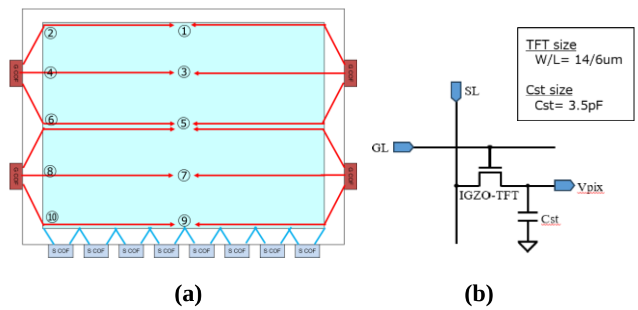


Figure 4. (a) Simulation points within the panel and (b) Equivalent circuit of the pixel.

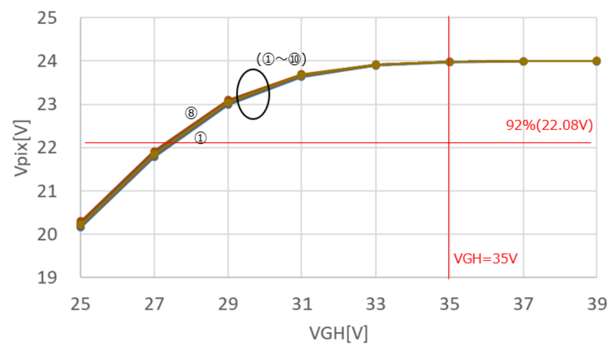


Figure 5. Pixel charging simulation results assuming Spectra 6 50Hz operation.

4. A1 size BP for E Ink Spectra™6 Plus High frequency driving IGZO-TFT design

Benefits of Spectra6 Plus driving:
In Spectra 6 Plus, the refresh rate is accelerated from 50 Hz to 125 Hz. This high refresh rate driving offers the advantage of reducing flicker during screen refreshes, thereby enhancing the overall visual experience and improving viewer comfort.

However, driving at high frequencies imposes limitations on the charging time for the pixels. This constraint can impact the ability to fully charge the pixels within the available time frame, potentially affecting image quality and overall display performance.

Circuit simulation of high frequency driving:
The data and gate waveforms for Spectra6+ are designed to work in harmony, ensuring efficient pixel operation, minimal errors, and enhanced visual performance. The careful consideration of voltage levels, timing, and waveform characteristics allows for improved reliability and quality in high-refresh-rate display applications.

Figure 6 illustrates the data waveform and gate waveform designed for the Spectra6+ system. Under the worst-case R/C load conditions, the horizontal scan time (1H) is 7.27 µs, with an on-time (Ton) of 6.0 µs. The timing has been optimized to mitigate the risk of charging errors, ensuring reliable operation and maintaining display performance.

Figure 7 presents the charging simulation results at 125 Hz for the Spectra6+ system. At a gate voltage (VGH) of 35V, the charging rate is measured at 95% under worst-case conditions, which exceeds the target specification of 92%.

Moving forward, we plan to implement this setting in the actual hardware to verify its effectiveness in reducing flicker during screen refreshes.

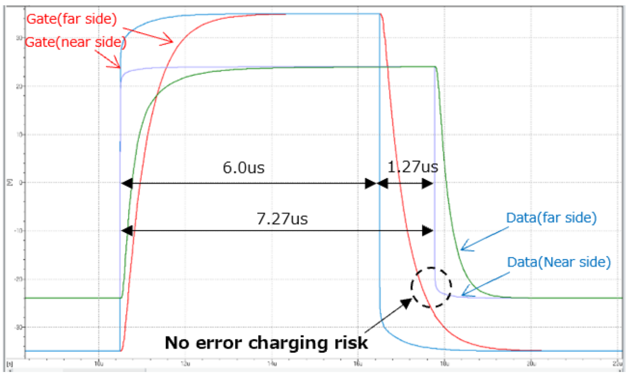


Figure 6. Source and Gate Waveforms for Spectra6+

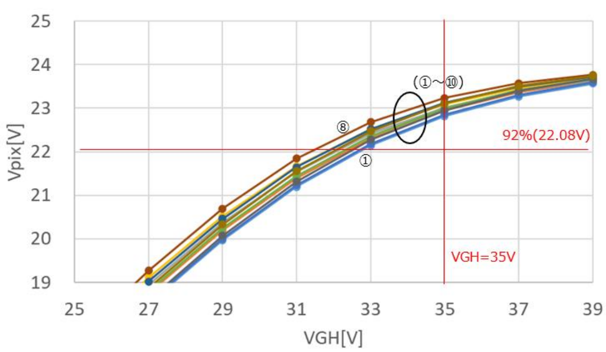


Figure 7. Pixel charging simulation results assuming Spectra6 Plus 125Hz operation

5. World's largest E Ink Spectra™6 display module

Sharp and E Ink have developed an A1-sized electronic signage module. Table 2 presents the basic specifications of the sample panel. This module supports full-color display capabilities via Spectra 6, demonstrating outstanding display quality. A photograph of the demonstration unit is shown in Figure 8. Currently, we are also in the process of developing a higher-resolution model.

Table 2. Specifications of demo sample panel

Screen Size (Active area)	40.5 inch, 594 x 841mm (A1)
Resolution	2160×3060
Pixel density	92 ppi
Drive Frequency During Image Switching	50 Hz, 125Hz

Figure 8. A1 size Full-Color ePoster (Spectra™6)

6. Conclusions

The combination of full-color Spectra™6 ePaper technology and the high mobility, low off-leakage, and high reliability of IGZO TFTs represents an optimal solution for achieving large-scale signage displays. By integrating E Ink's Spectra™6 with Sharp's IGZO TFT substrate, we have realized the world's largest A1 signage display.

Additionally, charging simulations have confirmed that this panel can be driven at the required 125 Hz with Spectra6+. This capability is expected to improve flicker during screen transitions, and if limited to 50 Hz, there is potential to drive even higher-resolution panels.

7. References

[1] HongMei Zang, et al., "Highly Saturated Color Electrophoretic Display" SID'23 DIGEST, 88-2 (2023)

[2] Hong-Mei Zang, et al., "Color Electrophoretic Displays" IDW'23, Vol30, EP1-1 Invited (2023)

[3] Fumiki Nakano, et al., "IGZO backplane for Full-color Electrophoretic Display" SID'23 (2023)

[4] Yohei Takeuchi, et al., "Application of Hot Carrier Degradation Tolerant IGZO to High Frequency LCD/ePoster" SID'24 Poster_P78 (2024)

[5] Yujiro Takeda, Shunsuke Kobayashi, Shogo Murashige, Kazuatsu Ito, Izumi Ishida, Shinji Nakajima, Hiroshi Matsukizono, Naoki Makita, "Development of high mobility top gate IGZO-TFT for OLED display." SID'19 Digest pp.516-519 (2019).

[6] Yoshihito Hara, et al., "IGZO-TFT Technology for Large-screen 8K Display" SID Digest, 53-3 706-709 (2018).