

# Touch Sensing and Graphics Processing in MicroIC Displays

I. Knausz, J. Wan, C. Verreen, B. Raymond, T. Weeks, A. Pearson, N. Rivers, T. Daniels, G. Bradshaw, C. Meyer, N. Cannon, N. Jain, C. Prevatte, E. Radauscher, M. A. Meitl, and C. A. Bower

X Display Company (XDC) Inc., North Carolina, USA

## Abstract

*MicroICs advance display backplane technology by offering superior power efficiency and functionality over TFTs. They integrate CMOS logic for enhanced features, utilize innovative driving schemes, and employ scalable mass transfer techniques. These improvements result in high-performance displays with excellent optical characteristics and opportunities for smart sensor integration, ideal for portable and wearable devices. MicroIC-driven displays enhance graphics processing with techniques like color quantization, additive rendering, and adaptive compression. These innovations reduce bandwidth, maximize visual quality, and boost real-time performance for interactive applications and gaming.*

## Keywords

microLED; microIC; touch; graphics

## 1. Introduction

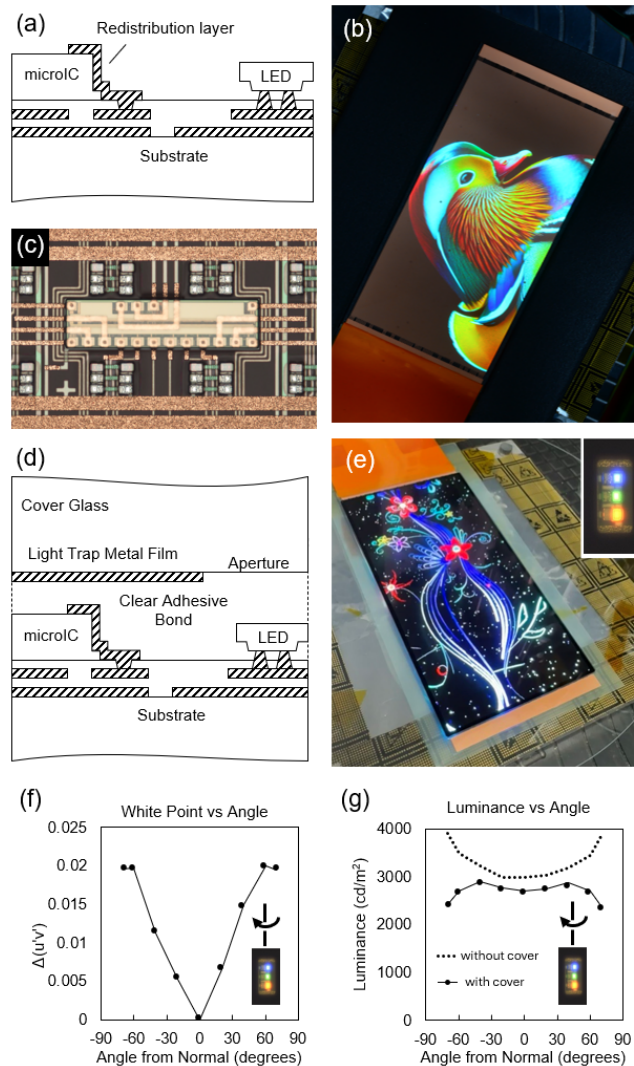
MicroICs represent a significant advancement in display backplane technology, providing a high-performance alternative to traditional thin-film transistors (TFTs). These integrated circuits offer superior power efficiency and enhanced functionality for both microLED and OLED displays.

MicroICs leverage single-crystal silicon to overcome TFT limitations such as high parasitic capacitance, resistance, and suboptimal transistor performance [1]. One of the key advantages of microIC technology is its lower emitter drive compliance voltage, which is an order of magnitude lower than conventional TFTs. This reduction directly minimizes parasitic losses and power consumption, which is critical for portable and wearable devices. Additionally, integrating complementary metal-oxide semiconductor (CMOS) logic unlocks groundbreaking features, including fully static memory that enables power savings in refresh rate, partial refresh, precise calibration, and increased color depth to meet stringent high dynamic range (HDR) standards.

MicroIC technology enables innovative driving schemes, such as a flexible hybrid pulse width modulation (PWM) and pulse amplitude modulation (PAM) approach. This method adds multiple

bits of color resolution while ensuring that microLEDs operate at nominal efficiency. Digital signal distribution enhances precision and nearly eliminates transient switching by removing analog sample-and-hold circuits, thus eliminating the need for complex voltage compensation and bulky row driver circuits.

Mass transfer techniques have made significant progress, with several assembly methods emerging, such as laser-assisted transfer, electrostatic transfer, stamp transfer, and fluidic assembly [2]. Among these, elastomer stamp transfer has proven to be a scalable, high-yield solution [3, 4]. This method uses a patterned, conformable elastomer surface to pick up and release microLEDs or microICs in large arrays using van der Waals forces [4]. Unlike serial assembly methods, this parallel approach enables mass transfer at the scale needed for display production. Precision



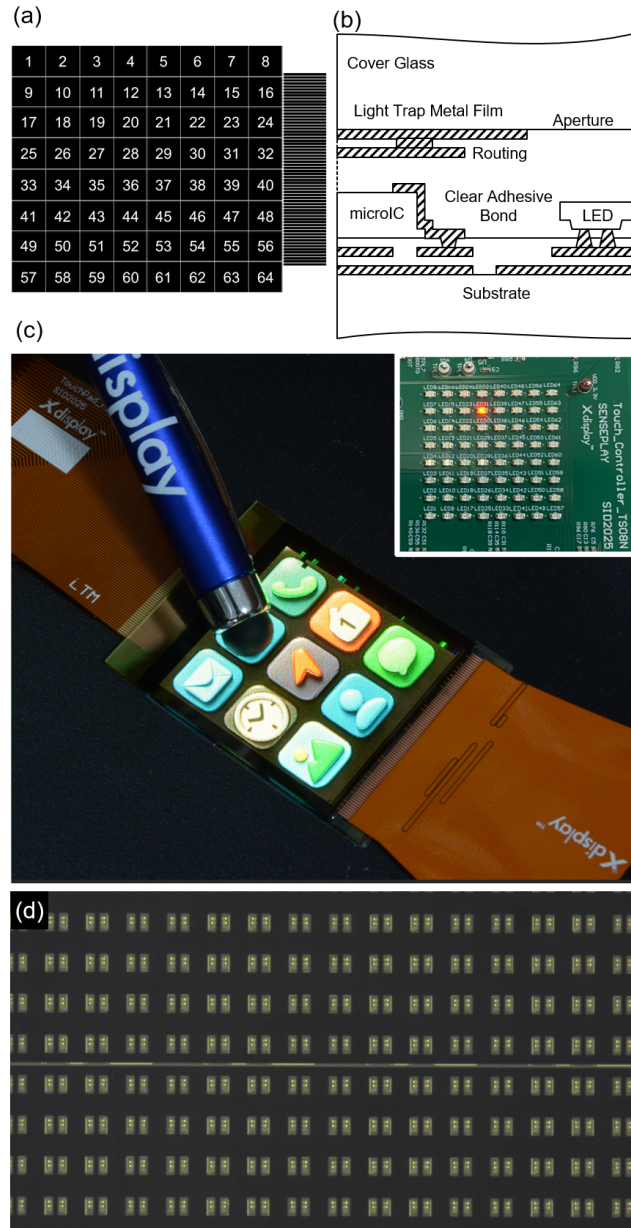
**Fig. 1:** microLED displays that use microICs to drive clusters of pixels. (a) schematic cross-section of the microIC and microLED integrated on a two-level wiring substrate. (b) photograph of a 5.1" 140 ppi cluster-driven microLED display. (c) micrograph showing a cluster driver microIC with RGB-stripe arrangement of redundant  $13 \times 20 \mu\text{m}^2$  microLEDs. (d) schematic cross-section of the microLED display with the contrast-enhancing cover glass. (e) photograph of the 5.1" 140 ppi display with the contrast-enhancing cover glass. The inset shows a micrograph of the RGB-stripe microLEDs emitting light through the aperture in the light trap metal film. (f) shift in white point measured with a spectroradiometer versus the viewing angle. (g) display luminance versus viewing angle with and without the cover glass. The subpixel orientation is shown in the inset.

equipment utilizes motion stages and microscope optics to align elastomer stamps relative to the microLED and microIC source substrates and the destination panel. Demonstrated transfer cycles of 10 seconds with a stamp transferring 562,500 devices per cycle support commercial production of mass-market displays [5].

A demonstration of microIC technology is embodied in a 5.1" microLED display showcased in **Figs. 1(a-e)**. The display is a  $640 \times 320$  array of pixels at 140 pixels per inch. The display is fabricated by elastomer stamp mass transfer of cluster-drive microICs and microLEDs onto a passive two-level glass wiring substrate produced by a leading panel manufacturer. This prototype utilizes a single, non-redundant, cluster-driver microIC within each  $4 \times 4$  cluster of microLED pixels. The subpixels have a redundant RGB-stripe arrangement and are comprised of red, green, and blue  $13 \mu\text{m} \times 20 \mu\text{m}$  flip-chip microLEDs [1], as shown in the **Fig. 1(c)** micrograph. The microLEDs are electrically interconnected to the wiring panel using pressure-concentrating spikes, or studs [6]. The microIC is electrically interconnected to the wiring panel by a thin-film copper redistribution layer. The microIC is fabricated in a 110-nm CMOS foundry process. The cluster-driver has an internal memory that stores 12 bits of data per color. Time division multiplexing [7] and binary-weighted pulse width modulation (PWM) are utilized to minimize power consumption while maintaining precision greyscale rendering. To achieve high contrast, a low reflectance coverglass that utilizes a patterned light trap metal film [8] is bonded to the display using optically clear silicone, as illustrated in **Fig. 1(d)**. The photographs of the display with and without coverglass, **Figs 1(e & b)**, are chosen to highlight the dramatic contrast improvement afforded by the light trapping technology. The inset in **Fig. 1(e)** is a micrograph of a single RGB-stripe subpixel shining through the patterned aperture in the coverglass. **Figs. 1(f & g)** show how the display white point and luminance change with viewing angle. The white point shifts towards blue/green as the viewing angle shifts away from normal incidence due to the wider emission patterns of the blue and green microLEDs compared to the red microLEDs [1]. In testing, this display delivers a peak luminance of 4,500 cd/m<sup>2</sup> and 99.84 percent coverage of the DCI-P3 color gamut, with a gamut ratio of 111.37 percent [1]. The display consumes 330 mW of power at 200 cd/m<sup>2</sup> with a 50-percent average picture level (APL), placing this prototype in the same class as other state-of-the-art emissive displays. Brightness and efficiency will continue to improve with improvements in the microLEDs [9] and advanced power saving features added to the microIC backplane.

## 2. Touch Sensing

A prototype 70 ppi microLED display with a touch sensing coverglass was presented at Displayweek in 2024 [10]. Here, we extend that technology to demonstrate a sixty-four electrode touch sensing coverglass, **Fig. 2(a)**, attached to a 1.6" 140 ppi microIC-driven microLED display. To maximize the fill-factor of the contrast-enhancing light trap metal, an additional thin-film metal wiring level is added to the coverglass, as shown in **Fig. 2(b)**. The additional routing level allows for small gaps between the light-trapping touch segments, **Fig. 2(d)**, enabling higher sensor resolution and enhanced touch performance, and allows for a small bezel. **Fig. 2(c)** is a photograph of the 1.6" 140 ppi display with the contrast-enhancing touch coverglass. This display is built using the same cluster-drive microICs and flip-chip microLEDs described earlier. The **Fig. 2(c)** inset is a photograph of the touch control board indicating contact by the stylus shown in the main image. **Fig. 2(d)** is an optical micrograph of the display in the off state. The center line is a gap between adjacent touch pads.



**Fig. 2:** Touch sensing using a segmented light trap metal film coverglass on a microIC-driven microLED display. (a) illustration of the 1.6" diagonal coverglass with an  $8 \times 8$  array of touch electrodes. (b) cross-section schematic of the two-level coverglass attached to the microLED display. (c) photograph of the 1.6"  $160 \times 160$ -pixel display with the functioning touch coverglass. The inset is a photograph of the corresponding  $8 \times 8$  LED array on the touch control board detecting contact by the stylus. (d) micrograph of the display in the off state. The center line is a gap between adjacent touch pads.

Future display architectures [10] allow touch electrodes and other sensors and actuators to connect with the microIC backplane. The multiplexing capability of the microICs facilitate comprehensive touch scanning, synchronized with display playback, and can improve performance by incorporating signal conditioning within the microIC.

### 3. Graphics Processing

Graphics processing in displays driven by microIC technology is making significant advances. These improvements focus on handling graphics data more efficiently, providing better visual quality and lower system power consumption. Methods to overcome current limitations in data bandwidth, power efficiency, and real-time display performance are presented.

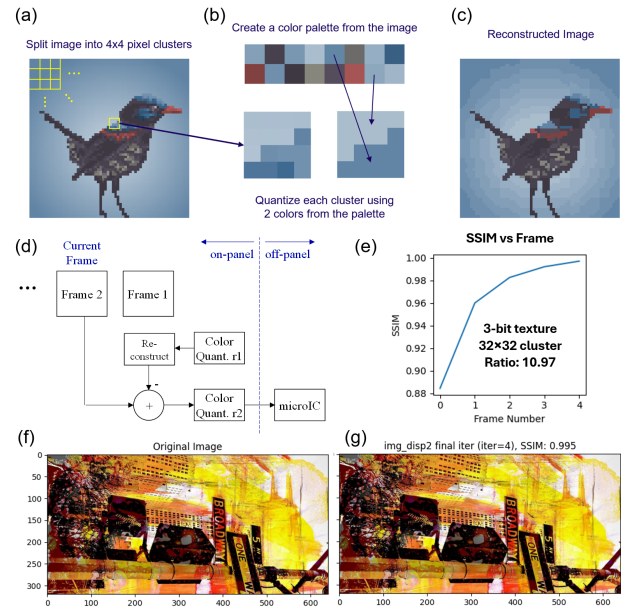
A well-known technique to compress data is color quantization [11], illustrated in **Figs. 3(a-c)**. Displays using a global color palette can limit image quality. Now, microIC displays can break the image down into smaller clusters of pixels, each with a local color palette. Using microICs to control these smaller groups of pixels allows the display to achieve enhanced color accuracy while reducing system-to-display bandwidth. Simulations have shown that dividing images into 32x32 pixel clusters, each with an eight-color palette, achieves a high compression ratio, approximately 11:1, while maintaining very good visual quality. Images can be further compressed by chroma subsampling, i.e. using higher-colored palette depth for the luma channel and using a lower depth for chroma channels.

Building on that is an innovation called additive rendering which can be used to compress video. Instead of sending complete image data for every frame, additive rendering only transmits color quantized changes between frames as described in the block diagram in **Fig. 3(d)**. The microIC then combines these updates to recreate the full image. This approach significantly reduces the amount of data needed for each frame, making it possible to achieve higher frame rates and even enabling wireless data transmission. This method is reminiscent of how early compressed images improved progressively, with image quality improving over a few frames as can be quantified by Structural Similarity Index Measure (SSIM) [12] or FLiP [13] tests. This is simulated for a 32x32 microIC-controlled cluster where the SSIM approaches 1.00 after a few frames as shown in **Fig. 3(e)**.

Adaptive additive rendering further improves image quality, especially for scenes with areas of slow movement. This technique continuously evaluates the visual quality during compression. If it detects potential quality loss, the system automatically adjusts its settings, either by using smaller pixel clusters for color quantization or sending uncompressed data. This ensures high visual quality for both fast-moving and slow-moving scenes. The resulting image is indistinguishable from the original even for the most difficult of images with gradients and sharp lines, as shown in **Figs. 3(f, g)**.

Additionally, the high-density CMOS logic circuits available to a microIC designer provides new ways to numerically represent pixel data. Traditional linear digital-to-analog converters (DACs) need high bit-depths to display images with a wide range of brightness. A new approach uses non-linear integer representation, simplifying the number of bits required and making data easier and faster for the microIC to process. This method does not require complex calculations such as multiplication or division, keeping the processing load inside the microIC easy to manage.

Integrating these graphic processing enhancements directly within microIC-driven displays is a major step forward. Embedding these advanced processing features directly in the microIC allows the display itself to handle some rendering tasks without relying heavily on external graphics processors (GPUs). This reduces video link bandwidth and improves frame rate, making these displays ideal for interactive applications and gaming where rapid response times and smooth images are crucial.



**Fig. 3:** (a) an original non-compressed image, (b) color palette selection and assignment, (c) reconstructed color quantized image, (d) block diagram for the additive rendering algorithm, (e) SSIM results versus frame for a still image, (f) original image, and (g) image result after 4 iterations of adding additional information and reconstruction.

These advancements can also enable high-frame-rate video connections. This capability is particularly beneficial for augmented reality (AR) and virtual reality (VR) applications, where quick updates and high-quality visuals are essential for an immersive experience.

Overall, integrating additive rendering, advanced color quantization, adaptive compression, and non-linear numeric representations into microIC-driven emissive displays represent a significant technological advancement. These techniques collectively offer visually excellent image quality, efficient data management, and faster processing speeds, preparing microLED technology for widespread use across various applications—from portable electronics to large-scale immersive displays.

### 4. Conclusion

MicroICs transform display backplane technology by surpassing TFTs in power efficiency and functionality. Integrating CMOS logic, innovative driving schemes, and scalable mass transfer techniques, they deliver high-performance displays with superior optical characteristics and smart sensor integration. Additionally, MicroIC-driven displays enhance graphics processing through color quantization, additive rendering, and adaptive compression, reducing bandwidth usage while maximizing visual quality. These advancements significantly improve real-time performance for interactive applications and gaming, making MicroICs a key technology in the evolution of modern displays.

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