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High Performance MicroLED Displays with Mass-transferred MicroICs

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ABSTRACT

There is a growing consensus that microLED will become the next major flat panel display type. At present, leading companies are demonstrating steady progress against the technological challenges that historically impeded the commercialization of microLED displays, such as mass transfer in manufacturing and fabrication of efficient micron-scale optoelectronic devices. Equally important is the pixel drive circuitry needed to control the microLEDs efficiently and reliably in these displays. Mass transfer for microLED displays most frequently refers to the process used to distribute microLEDs across a panel substrate, but it can also open entirely new advantageous possibilities in backplane design. Mass transfer of microIC drivers as pixel engines for microLED displays is gradually receiving increased attention as a path toward unmatched efficiency, dynamic range, and brightness.

1 INTRODUCTION

MicroLED displays offer performance advancements in comparison to the incumbent LCD and OLED displays. Emissive microLED displays will be bright, colorful, power efficient, fast, and reliable. MicroLEDs also enable novel transparent, tiled, and ultra-thin displays. Beyond displays, researchers are developing novel applications spanning biomedical, optogenetics, and visible light communication [1]. Mass production of microLED display technology necessitates that display makers attain new competencies. Primary among those competencies is a scalable and high throughput mass transfer technology that can assemble diverse microdevices in a precise and massively parallel approach, while delivering extremely high yields. Display makers also must develop display architectures, and associated pixel circuits, that are optimized to take advantage of microLEDs.

Many display makers are extending thin-film transistor (TFT) technology to microLEDs, but some groups are investigating the possibility of applying the same mass transfer technologies to tiny high-performance silicon integrated circuits, microICs, for driving the microLED pixels. To integrate microLEDs with microICs, different approaches have been investigated such as such as monolithic LEDs with Si CMOS [2, 3], selective epitaxy, chip-on-board [4], wafer-level bonding [5] etc. However, these approaches suffer from issues related to scalability, cracks emanating from the CTE mismatch or inadequate LED performance. In reference to mass transfer technologies for massively parallel pick-and-place, the technological landscape is widespread, ranging from elastomer, electrostatic, magnetic, adhesive, micro-fluidic, role-to-role, laser, etc. [1]. The recent microLED technological progress has been impressive, and increased commitments from key stakeholders in the value chain can lead to mainstream adoption for consumer display applications.

Micro-transfer printing (μTP) technology stems from the pioneering work done in Professor John Rogers' laboratory in the mid-2000s [6, 7]. Patterned elastomer stamps provide a low-cost, deterministic and a scalable solution for mass transfer of micron-scale devices, with throughputs exceeding hundreds of millions of units per hour [8]. Additionally, the μTP process offers high precision with successful demonstration of alignment distributions within ± 1.5 μm 3σ [9]. Furthermore, the printing process does not require liquids, elevated temperature, or vacuum. The process is versatile and has enabled printing of microLEDs on myriad non-native substrates ranging from fabric, foil, paper and flexible plastic [10, 11].

2 EXPERIMENT

Individual red, green and blue microLEDs and Si microICs are fabricated on their respective native substrates (or source wafers). Thereafter, they are transfer printed onto an intermediate non-native wafer (referred to as the pixel engine wafer). This intermediate wafer is populated with several of such pixel engine micro-components, where each pixel engine may include red, green and blue microLEDs and a microIC. In lateral LEDs, the light emission is through the transparent substrate and in flip-chip LEDs, the emission is primarily upwards of the electrical bond interface.

The display fabrication begins with the deposition of first level metal on a transparent glass substrate followed by the subsequent deposition of a dielectric layer and a thin-film of semiconductor-grade resin that serves as the attachment adhesive for microLEDs and microICs. A patterned elastomer stamp is used to transfer the microLEDs and the microICs onto the display substrate.

The blue and green microLEDs use InGaN quantum-wells and are grown on Si substrate and the red microLEDs use AlGaInP active materials grown on a GaAs substrate. The microLEDs are fabricated as 8 x 15 μm^2 lateral microLEDs and are transferred to the display substrate, as described in detail elsewhere [10,11]. The microICs are based on a 180nm SOI-CMOS foundry process and are released from their native Si substrate, as described elsewhere [12]. These microICs have a footprint of ~ 90 x 50 μm^2. The display fabrication is completed by deposition of a second level metal redistribution layer which interconnects the surface electrodes of the microLEDs and the microICs to the first metal level through a via in the dielectric layers. A custom flex cable is ACF-bonded onto the display and a FPGA is used to control the display.

3 RESULTS

A self-emissive 5.1" 70PPI display is demonstrated using transfer-printed red, green and blue microLEDs and microICs. Fig. 1(a) is a schematic of the display architecture. Transfer-printed microICs serve as the column and row drivers for the display. Each set of red, green, and blue subpixels are controlled by a single pixel driver microIC. The video data is transmitted to the pixel drivers in digital format. The pixel driver microIC has a 48-bit memory and receives 16-bits of digital data per color during the data loading. The subpixel brightness is controlled using 14-bit PWM and the microLED drive current is set using 2-bits. Fig. 1(b) is an optical micrograph of an energized 2x2 pixel array. In this example, each pixel includes redundant emitters, drivers and row/column wiring. Fig. 1(c) is a photograph of the 320RGBx160 in operation. The measured red, green, and blue subpixel yields are 100%, 99.996% and 99.998% respectively. As shown in Fig. 2, the display exhibits wide viewing angles without color shifts or reduction of luminance.

4 CONCLUSIONS

Displays based on assemblies of microscale, wafer-fabricated components, such as microLEDs and microICs, can achieve efficiencies, brightness, and lifetimes that are inaccessible to conventional flat-panel displays. The required mass transfer technologies must be high yield, cost-effective and well-suited for handling micron-scale devices. Elastomer stamp micro-transfer printing is an assembly technology with the potential to meet these demands. Here, a lab-scale prototype 5.1" 70PPI display using mass transferred microLEDs and microICs is demonstrated.

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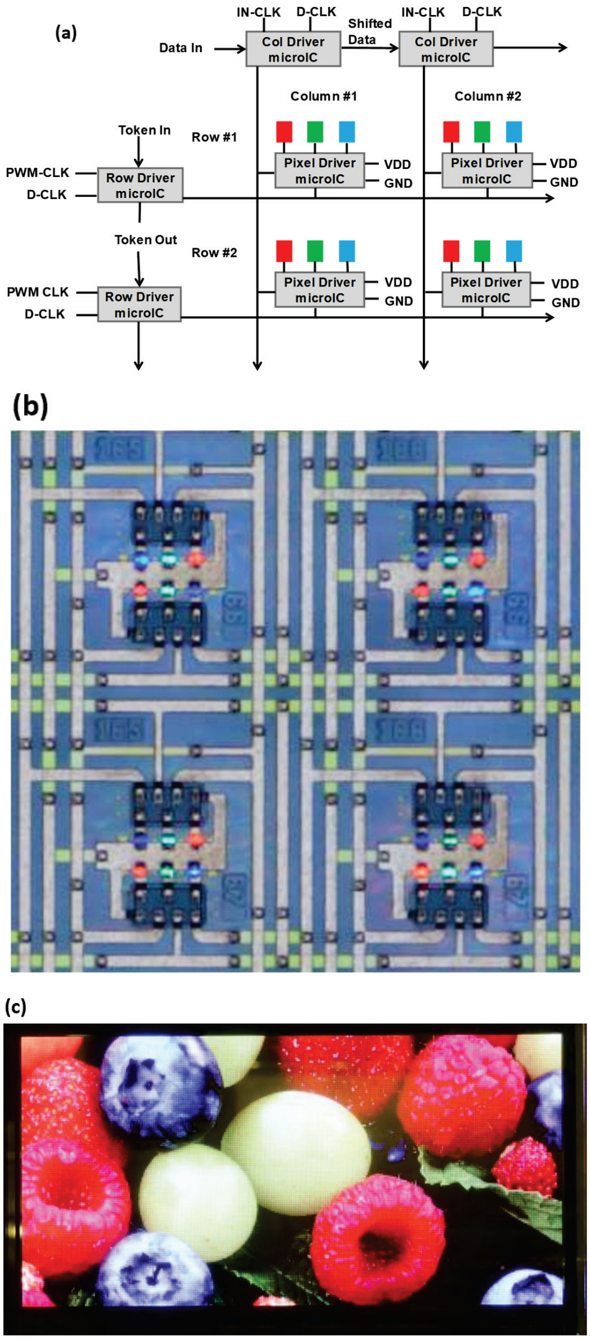

Fig. 1 (a) schematic of the microIC display architecture, (b) a optical micrograph of a 2x2 pixel array and (c) a photograph of the 320RGB x 160 microLED display driven by microICs

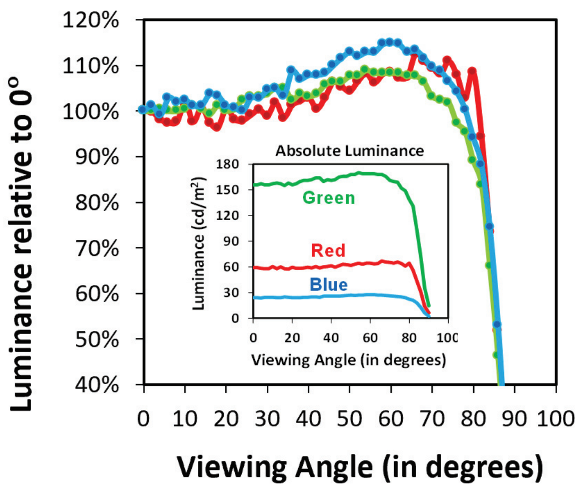

Fig. 2 Relative luminance versus viewing angle. The inset shows the absolute luminance versus viewing angle.