P-OLED Microdisplay Technology

Ian Underwood*, Alastair Buckley, Chris Yates

MicroEmissive Displays Ltd, Scottish Microelectronics Centre,

West Mains Road, Edinburgh EH9 3JF, United Kingdom

Phone: +44 (0) 131 650 7764, E-mail: i.underwood@microemissive.com

Abstract

The highly integrated nature of polymer based organic light emitting diode (P-OLED) microdisplay technology, coupled with low voltage and low power electroluminescent light generation, combine to offer a very promising technology for use in portable and personal electronics products. We briefly describe the technology before discussing how to engineer the color gamut using white-emitting polymer materials, microcavity device structure and color filter absorbance.

1. Introduction to microdisplays

A typical definition of a microdisplay is *"a very small display that is intended to be viewed with the assistance of optical magnification"*. Microdisplays are usually full-color active-matrix displays of less than 25mm diagonal that are capable of displaying images of television quality or better. They are utilized in two main classes of application. Projection systems create a large real-image of one or more microdisplays on a flat surface where it can be viewed by a number of people. Near-to-eye (NTE) systems create a magnified virtual-image of a microdisplay that, when placed in proximity to the eye, can be viewed by a single individual. NTE systems can be designed to be monocular or binocular, offering the possibility of generating true stereoscopic images. Armitage et al [1] offer a comprehensive introduction to the microdisplays.

Like many display technologies, a microdisplay technology is largely defined by two main factors, (i) the electro-optical or display technology, and (ii) the electronic or active-matrix backplane technology. Electro-optical technologies that have been used to produce microdisplays include those based on liquid crystal (LC) effects, generally either nematic or ferroelectric in nature, micro-mechanical systems, inorganic EL, and more recently organic electroluminescence EL. Active matrix backplane technologies have included LTPS and HTPS on glass, CMOS and related technologies on crystalline silicon (x-Si) and silicon-on-insulator (SOI) as well as transferred silicon. The choice of display technology defines whether a microdisplay is *emissive* or *modulating*. LC and MEMS based devices modulate an external light source, whilst EL and OEL generate light at the pixel as required. The choice of backplane technology defines whether a modulating display is *transmissive* or *reflective*.

2. P-OLED/CMOS Microdisplays

P-OLED/CMOS microdisplays combine the advanced technology of CMOS electronics with the simplicity of manufacture of P-OLED systems. Acceptable levels of light emission can be achieved using operating voltages and power consumption levels that are highly attractive for mobile consumer devices. Hundreds of individual displays can be produced on a single wafer using standard wafer processing techniques.

2.1 Competitive advantages

P-OLED/CMOS offers high levels of electronic and optical integration, very low power consumption and impressive image quality. In particular the image quality is perceived as higher than other NTE microdisplays due to high pixel fill factor, fast switching speed allowing for high refresh rates, high intrinsic contrast ratio, and clarity of image due to the simple and direct nature of the optical viewing system. A very small module form-factor is possible as the need for external driver IC's and light source is removed.

2.2 Applications

P-OLED/CMOS is a very promising technology for consumer NTE applications including (a) digital viewfinders for cameras and camcorders, and (b) hands-free/head-mount display for video glasses used with personal DVD, MP4, PMP and mobile phone.

2.3 Device structure

P-OLED displays can be divided into those that emit light through a transparent electrode, usually ITO, deposited on glass (bottom-emitting) and those that emit light through a thin semi-transparent metallic electrode deposited on top of the active layers, (top-emitting). In a P-OLED/CMOS microdisplay the substrate is opaque so the microdisplay is top-emitting. The top metal layer on the CMOS wafer provides the anode of the device as well as a highly reflective back surface. In general this anode must be coated with a high work-function material in order to provide efficient injection of holes into the organic layers. A thin, highly conducting metal coated with an ultrathin electron-injecting interface, such as lithium fluoride, forms the cathode. Accurate control of charge injection at both electrodes is key to optimising the efficiency, lifetime, and operating voltage of the device. The operating voltage in particular is of importance for CMOS based microdisplays where a maximum operating voltage is defined for a iven CMOS process. Figure 1 illustrates MED's P-OLED microdisplay structure with pixelated opaque CMOS substrate, hole injection and hole transport layers, white emitting layer, transparent cathode and color filter pixels. It is important to understand that the display, wherein the emitting layer is sandwiched between the highly reflective anode and semi-transparent cathode, constitutes a microcavity or optical resonator. This structure has a strong influence on the achievable color gamut and white point. In Section 3 we discuss the impact of such a microcavity device on our preferred method of color generation.

3 Color generation

Color pixels can be achieved by, for example, sub-pixelation by patterning separate areas of red (R), green (G) and blue (B) emitting materials, by the use of a white emitter with patterned RGB color filters (or indeed RGBW filter pattern) and by use of a blue emitter with B→G and B→R color converters placed over two of the three sub-pixels. RGB emitters are usually the preferred method. However, the small pixel pitch in microdisplays (3 sub-pixels in a 10μm to 20μm pitch) presents serious technological challenges to this approach.

We have chosen to use a white emitter with patterned RGB color filters. This color-by-white method has advantages for microdisplays. It offers the simplest manufacturing process with no need to pattern the active material and avoids differential color-aging, as would be the case for patterned RGB emitters.

The use of RGB sub-pixels on the microdisplays relies on the observer integrating the emitted light spatially to produce the perceived image at the eye. In particular this means that the display can be well characterized by the RGB color coordinates, (in, for example, CIE 1931 XYZ color space), together with the color coordinates of the white point, produced when all sub-pixels are fully on. This color gamut and white point are determined by the interaction of three specific spectral influences – (1) the spectral shape of the basic emission spectrum of the underlying polymer, (2) the spectral shape of the relative outcoupling from the microcavity to the filter layer, and (3) the relative absorption / transmittance of the color filters.

The polymer composition determines a base emission spectrum that is then modified through microcavity coupling to give the fundamental device emission spectrum. In a full color microdisplay this emission spectrum is then modified by color filter absorption to give RGB emitting pixels. With accurate knowledge of the optical properties of all constituent layers the latter two points can be combined to give the individual outcoupling of each sub-pixel.

White-emitting P-OLED materials can be synthesized by polymerizing monomer units with different base emission spectra. Two options are widely available, namely, two-component systems where blue and red chromophores overlap to give a white emission, and three-component systems where blue, green and red chromophores overlap to give a white emission. Figure 2 shows the basic emission spectra of typical two- and three-component systems. In general it is believed that three component systems should offer more flexibility in color tuning than two component systems. This may be the case for bottom-emitting P-OLED displays, where cavity effects are less obvious. However, in top emitting P-OLED structures where microcavity effects are relatively strong, a full and balanced CIE gamut may be achieved uisng a two-component system.

The relative spectral outcoupling, from an emitter placed within a microcavity, will in general contain a peak at some wavelength. The spectral position of this peak is a strong function of the thickness of the cavity and the width of the peak is a function of the finesse of the cavity. This is illustrated in Figure 3a where the relative spectral outcoupling is plotted for the same device but with a change in the metal anode, producing a cavity with greater finesse. This illustrates the point that a change in the cavity properties can allow greater outcoupling, and thus a more efficient device, but at the cost of more strongly modulating the basic emission spectrum. It is also worth noting that the inverse of the relative outcoupling can provide an indication as to the optimum basic emission spectrum of the polymer, Figure 3b. The product of the emission spectrum and the outcoupling from the cavity, determines the light reaching the color filters. Thus an emission spectrum similar to the inverse of the outcoupling would theoretically produce a uniform spectral emission, before modulation by the color filters. Such an emission spectrum is not feasible in practice, but inspection of Figure 3b clearly indicates the relative merit of using a two-component polymer. Figure 3c demonstrates the effect the cavity thickness has on the white point for displays with high and low finesse cavities. Varying the thickness from 120nm to 60nm moves the white point from a red to blue color via white. As would be expected, the effect is greater for the cavity with greater finesse. These considerations indicate that the combination of polymer and cavity requires careful engineering in order to produce a device that has a sufficient color gamut whilst operating at a feasible voltage.

At the simplest level the color filters modulate the emission spectrum from the cavity by transmitting or absorbing the particular wavelengths. A more complicated analysis would model the entire device stack, and predict the output of each sub-pixel including color filter. In either case the bandwidth of transmittance of the filter will determine the saturation of the particular color. Reducing the bandwidth has the effect of increasing the saturation of the color and hence increases the possible color gamut of the display. In general this can be achieved by increasing the thickness of the absorbing layer within the filter. However, this has the effect of reducing the luminance of the sub-pixel and hence altering the color balance and white point of the display. Typical transmittance spectra for an RGB filter set are shown in Figure 4.

Since the microdisplay relies on spatial integration by an observer, the relative luminance values of the individual sub-pixels will determine the white point of the display. The white emission spectrum is simply the sum of the emission spectra from the three sub-pixels. In an ideal case the luminance emitted from each sub-pixel would be identical, and whilst this is very difficult to achieve, an acceptable gamut and white point can be achieved with a two-component polymer system. Figure 5a shows the color gamut and white point, together with the conjugate colors (cyan, magenta, yellow), for a typical microdisplay based on a two-component polymer system, at a reasonable cavity thickness of 100nm. The color gamut is sufficiently large for most NTE applications and the white point is very close to CIE ‘E’ illuminant (0.333, 0.333). In contrast, Figure 5b shows the equivalent data for a device with the same structure but based on a three-component polymer system. At the same cavity thickness the gamut is severely shifted towards the yellow region of the color space. Reducing the cavity thickness of this device to 50nm produces an acceptable gamut but such a device would place very high tolerance limits on any production process.

4. Conclusions

We have outlined the nature of microdisplay technology and its applications then described the constraints of building a P-OLED device on a CMOS substrate and our choice of color-by-white for color generation. As a consequence of device constraints, color tuning is a function of three main factors. We have highlighted the factors that must be understood in order to produce a microdisplay with wide color gamut and an acceptable white point. A consequence of the dependence of the final microdisplay emission on the basic emission of the polymer and the coupling of the microcavity would suggest that future developments in materials should be combined with accurate modeling of the device in which the material will be implemented. We can envisage a situation in which polymer material sets are tailored to particular device architectures.

5. Acknowledgements

This work was carried out at MicroEmissive Displays Ltd in the UK.

6. References

[1] D. Armitage, I. Underwood and S.T. Wu, "Microdisplay Technology", Pub. Wiley, UK, 2006.

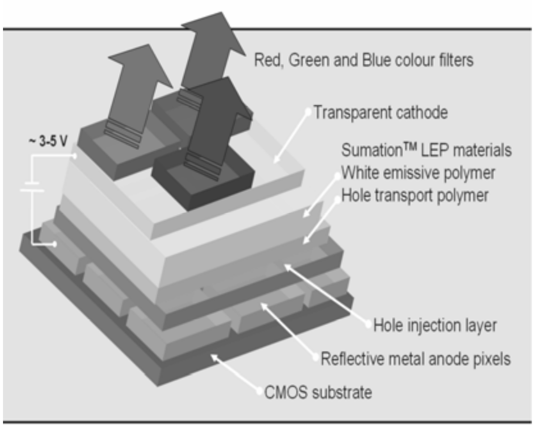

Figure 1. Schematic structure of the MED Microdisplay.

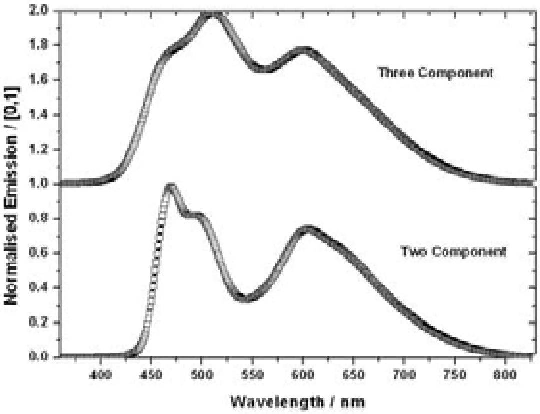

Figure 2. Typical basic emission spectra for two- and three-component polymer systems.

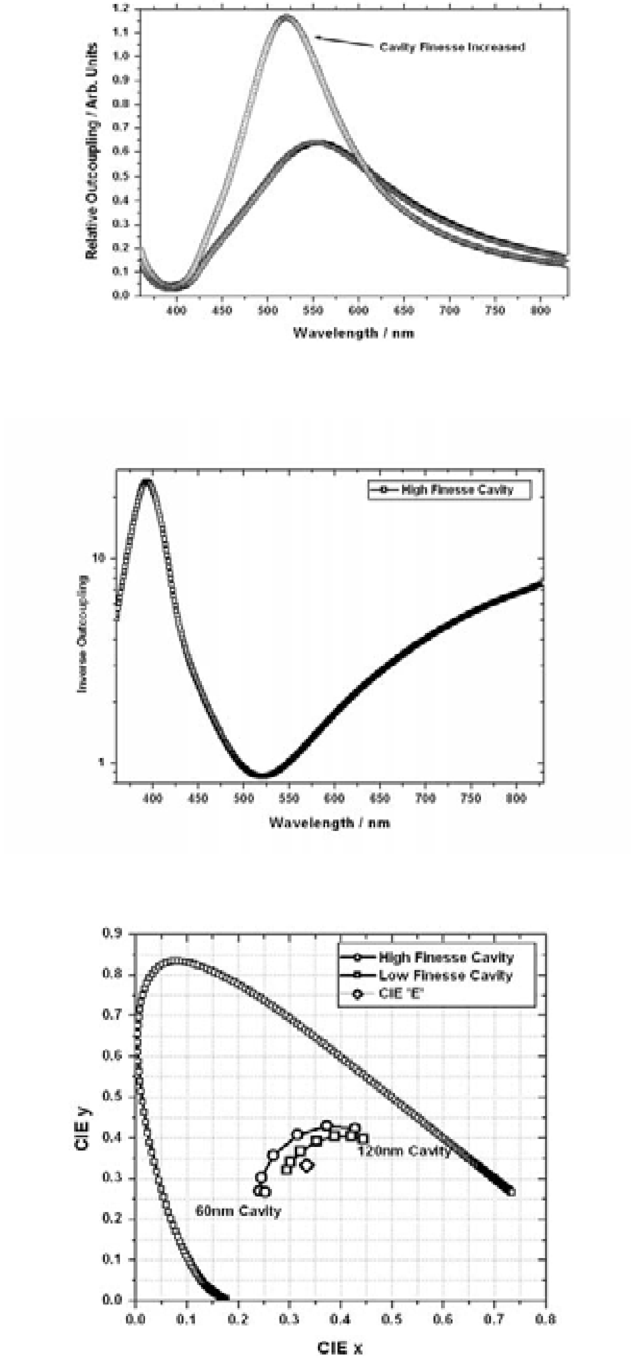

Figure 3. Top - relative spectral outcoupling from a high and low finesse cavity. Center - inverse of the relative outcoupling for a high finesse cavity. Bottom - tunability in the white point as a function of cavity thickness for high and low finesse cavities.

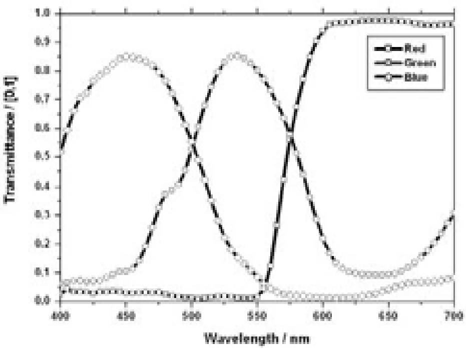

Figure 4. Typical transmittance spectra for an RGB filter set.

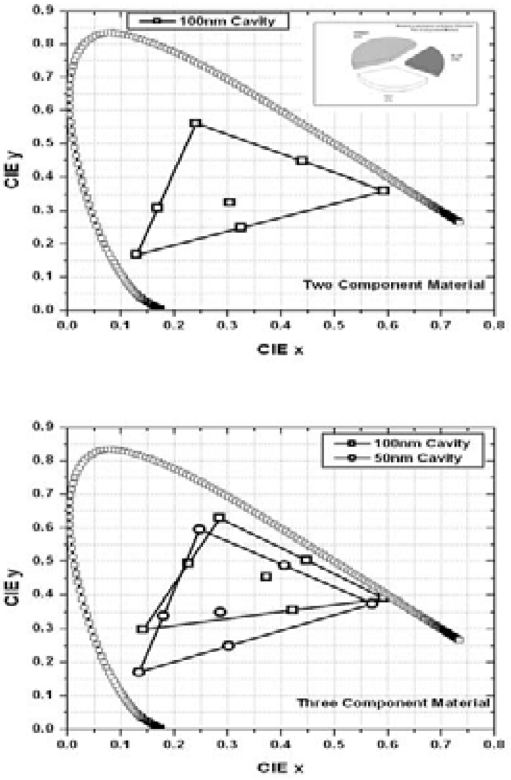

Figure 5. Top - color gamut and white point achieved by a microdisplay based on a two-component polymer system (inset shows relative luminance balance). Bottom - color gamut and white point achieved by a microdisplay based on a three-component polymer system at two different cavity thickness