True Color Control of a Multifunctional MicroLED Display

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Abstract

Opportunities to implement True color and Ambient light sensors using microPhotodetectors in-plane with microLED emitters are shown to overcome limitations of state-of-the-art OLED displays. A microPhotodetector can be augmented to enable True color and light source discrimination through Ambient Light sensing. It's integration into an analog frontend is demonstrated and its advantages from the distributed microIC control architecture of microLED displays are shown. Finally, we give some use case examples and show the benefit to overall user experience for microLED displays.

Author Keywords

microLED display, embedded sensing, system architecture, ambient light sensing, true colour sensing

1. Objective and Background

The human eye is an outstanding accurate color sensor. It is sensitive to a wide range of colors and can distinguish millions of different hues. It uses three types of cone cells (red, green, and blue) to perceive color, which correspond to the primary colors of light. It can adapt to different lighting conditions, adjusting its sensitivity to maintain the same color perception in varying environments. Due to all those properties adjusting displays to achieve exact and consistent color reproduction is an essential element to improve overall user experience (1).

The method of choice to gain information about the illumination environment and the true color of emissive displays is the use of low-channel count spectrometers called true color and ambient light sensors. This technology employs advanced color sensors that mimic the human eye's response to light as closely as possible, and for ambient light sensing employ more channels to distinguish between different light sources, enabling to identify them.

By accurately measuring ambient light and adjusting the display's white balance and color settings accordingly, true color sensing helps keep color fidelity across different lighting conditions.

The importance of this technology is evident for various applications, from smartphones and tablets to monitors and televisions. In professional settings, such as graphic design and video editing, precise color representation is essential for producing high-quality work. For everyday users, true color sensing ensures that photos, videos, and other media are displayed with vibrant and realistic colors, enhancing visual quality.

In modern OLED displays, true color and ambient light sensors are placed behind the display (behind OLED called BOLED) to hide the optical aperture of the sensor since there is not enough space between the emitters for a sensing element (2).

With the implementation of foldable OLED displays, the transmittivity of the full OLED stack is vastly reduced to 0.1% making BOLED sensing even more challenging. Main reason for this low transmittivity is the high density TFT backplane and the color filter on encapsulation (COE) for antireflection coating (3).

2. Implementation

In this work we would like to outline the opportunities for true color and ambient light sensing coming from the implementation of microDiscrete sensors in a microLED type architecture as outlined in Figure 1 from (2).

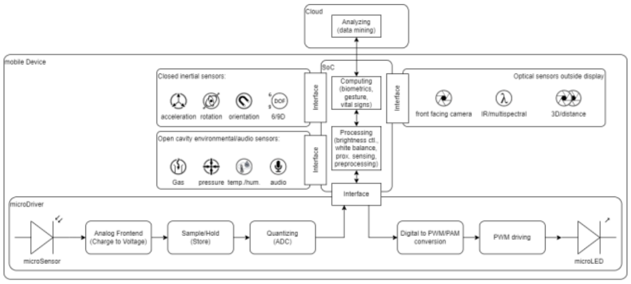

Figure 1. Top-Level Architecture Diagram of a mobile system using a microLED display with embedded sensing.

The microSensor element shown in Figure 1 comprises of a discrete micro transferrable detector element integrated into an equivalent way like the microLED. The overall technology integration scheme is shown in Figure 2.

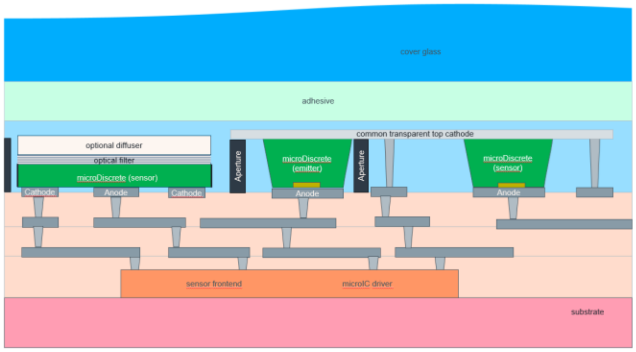

Figure 2. Cross section of technology scheme for microLED display with integrated microSensor. Optional diffusing medium for improving optical performance is included as well.

The microSensor consists of the combination of a single crystalline backside illuminated Si-photodetector with an interference filter deposited on the backside of the diode. An optional Lambertian diffuser layer is guaranteeing a good and constant light sensing performance across all angles of incoming light. The microSensor is manufactured using a high responsivity Silicon-On-Isolator process technology developed for medical imaging. It only uses one contact and one metal layer to enable the electrode connections of the detector Anode and Cathode to the flexible substrate and the underlying metallization layers which connect the sensor to the microIC frontend similar like the microLEDs are connected to the microIC driver in the same die (Figure 2).

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The Scanning Electron Microscope (SEM) micrographs in Figure 3 and Figure 4 illustrate the internal structure of the interference filters which cover the microSensors and are designed in such a way that the overall spectral response of the convolution of the Silicon spectral responsivity and the filter response give the required spectral sensitivity.

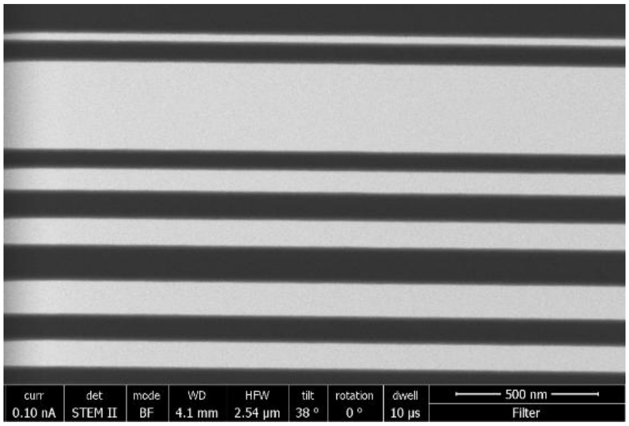

Figure 3: Cross-section of an interference filter showing consecutive high-refractive index and low-refractive index layers defining the filter characteristics.

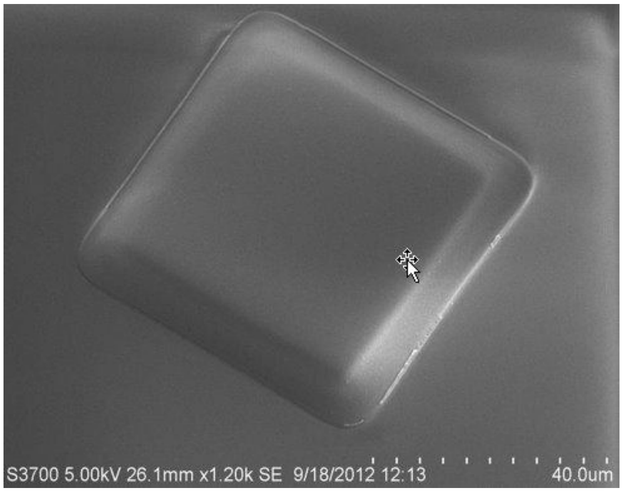

Figure 4: Top view of a filter on top of a substrate. The boundary is sloped due to the lift-off mask process used in this example.

Those filters need to provide highly customizable optical transmission characteristics which enable the modification of the rather flat spectral quantum efficiency response of a typical Silicon photodetector to the required spectral responsivity for use as True color or Ambient Light sensor.

To reach low color detection errors the requirements on those interference filters in terms of stability and reproducibility are very tight and result in the need for a very tight and accurate process control of the optical properties (n, k) and thickness of the filter layers as shown in Figure 3.

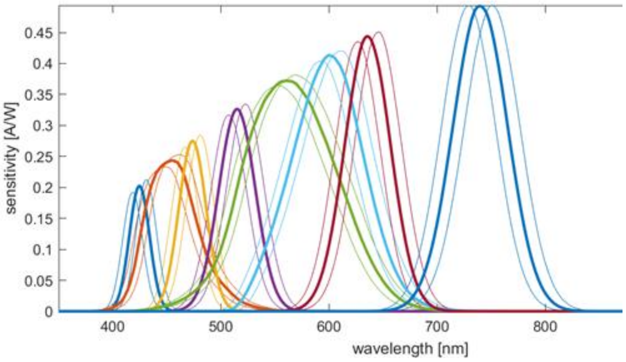

Figure 5: Overview of spectral relative responsivities of a combination of 8 optical channels $\boldsymbol{ch_i}$ consisting of eight different interference filters put on identical Si photodetectors **(4)**.

The resulting sensor channel configuration is given in Figure 5. Three of the eight channels are close to the X, Y, Z tristimulus spectral response functions of the cone cells in the human eye (5). Together with the other five channels one can setup a transfer matrix calibration equation

$$\begin{pmatrix} \boldsymbol{X} \\ \boldsymbol{Y} \\ \boldsymbol{Z} \end{pmatrix} = \begin{pmatrix} \boldsymbol{a_{1,1}} & \boldsymbol{a_{1,2}} & \boldsymbol{a_{1,3}} & \boldsymbol{a_{1,4}} & \boldsymbol{a_{1,5}} & \boldsymbol{a_{1,6}} & \boldsymbol{a_{1,7}} & \boldsymbol{a_{1,8}} \\ \boldsymbol{a_{2,1}} & \boldsymbol{a_{2,2}} & \boldsymbol{a_{2,3}} & \boldsymbol{a_{2,4}} & \boldsymbol{a_{2,5}} & \boldsymbol{a_{2,6}} & \boldsymbol{a_{2,7}} & \boldsymbol{a_{2,8}} \\ \boldsymbol{a_{3,1}} & \boldsymbol{a_{3,2}} & \boldsymbol{a_{3,3}} & \boldsymbol{a_{3,4}} & \boldsymbol{a_{3,5}} & \boldsymbol{a_{3,6}} & \boldsymbol{a_{3,7}} & \boldsymbol{a_{3,8}} \end{pmatrix} \begin{pmatrix} \boldsymbol{ch_1} \\ \boldsymbol{ch_2} \\ \boldsymbol{ch_3} \\ \boldsymbol{ch_4} \\ \boldsymbol{ch_5} \\ \boldsymbol{ch_6} \\ \boldsymbol{ch_7} \\ \boldsymbol{ch_8} \end{pmatrix} \quad \textbf{(1)}$$

giving the X, Y, Z tri-stimulus components of the sensed ambient light color with high accuracy. A comparison to a much larger high-precision chroma meter (CL-200A) reveals a typical error of the correlated color temperature dCCT of <2% with typical errors <1% for most luminaires except some halogen and fluorescent light sources (4). Thus, light source discrimination via sensing of special spectral features of different possible light sources like sun, incandescent, fluorescent or LED light is easily possible. A combination of eight different interference filter types on top of eight microSensors would thus already enable a perfectly accurate True color and Ambient light sensing capability within the display.

Since the microSensor element can be flexibly placed over the whole display backplane, there are numerous possibilities how to enable more complex sensing architectures within the overall system. A more complex arrangement which is fine-tuned to minimize the spectral reconstruction error in Eq. (1) is shown in Figure 6. The symmetry and size of the different channels IR, X, Y, Z, HgL, HgH, C and Flicker have been designed to minimize the error of the spectral reconstruction.

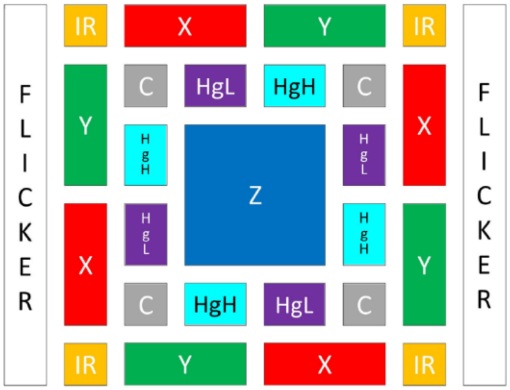

Figure 6: Sensor Field Array of TCS3530 True Color Ambient Light Sensor with Flicker Detection (4)

The power of this method can be seen from two examples of reconstructed spectra using the eight sensing channels, given in Figure 7 and Figure 8.

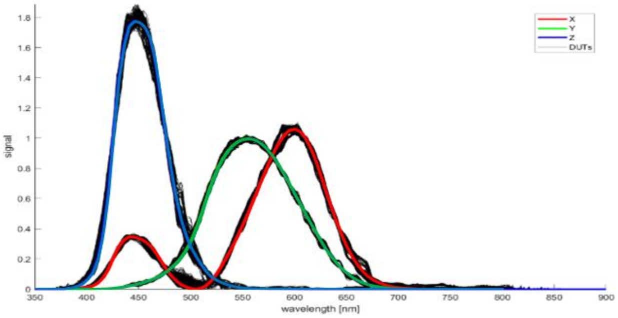

Figure 7: Reconstructed spectra of X, Y, Z spectral tristimulus sources (Red, Green and Blue) and measured response (Black, normalized to Y) of multiple devices showing small variability over different sensors after calibration

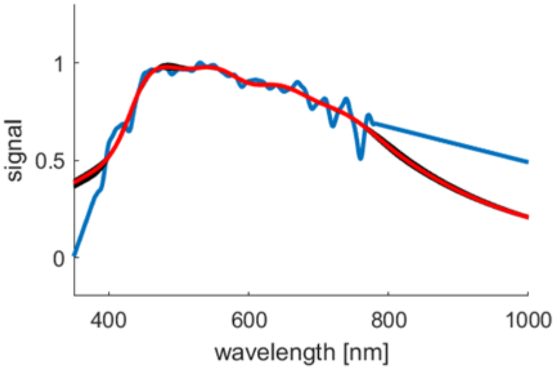

Figure 8: Reconstructed spectrum of multiple devices (Black normalized to 1), their average (Red) and comparison to high resolution spectrum (Blue) of Standard CIE Light Source D55

Those results outline again the remarkably high accuracy of the eight-channel spectral sensing principle.

3. Impact

The overall architecture outlined in section 3, enables an accurate, fully embedded color and ambient light sensing functionality within a microLED display using the same digital interface. When placing multiple True color and Ambient Light sensor instances within the display, advanced features like compensation of shadowing of the display, color gradients and inhomogeneities within the display and non-linear color degradation of the emitting elements over time could be compensated using the sensing feedback. Those functions could be enabled with only medium added complexity in the system. The requirements for microLED driver circuits in terms of CMOS technology node and associated complexity match very well with the requirements imposed by integrating sensing into the same architecture.

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