OLED/OPD-on-Silicon for Near-to-Eye Microdisplays and Sensing Applications

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ABSTRACT

We present microdisplays designed for high resolution on the one as well as for low power usage scenarios on the other side. Further information on application of organic semiconductor and CMOS technology in sensor devices for fingerprint scanner, organic photodiodes for near infrared sensing and fluorescence sensors will be presented.

1 INTRODUCTION

Within the last decade the display technology showed tremendous progress for LCD, organic LED (OLED), quantum dot LED and micro/mini-LED technologies. The color space, luminance and resolution of displays are key specifications which have been significantly improved by several display manufacturer. The microdisplays are a special type of displays which are used for virtual and augmented reality applications. Their small size but typically high resolution and luminance are achieved by using the OLED technology in combination with a CMOS backplane. This combination enables very low pixel sizes below 10µm as well as high luminance.[1] We present two different OLED microdisplay designed to enable a full color and high resolution as well as a monochrome low power display for mobile and power sensitive application.

The CMOS backplane technology offers various different microelectronic devices which can be integrated additionally to the active matrix and driving circuitry of the displays. Inorganic photodiodes can be placed into every pixel enabling a bidirectional microdisplay being able to integrate a display and camera within one device. This additional bidirectional feature can be used for eye-tracking in near-to-eye applications.[2]

Here we present a new derivative of this OLED on silicon technology using the CMOS features. Using advantages of CMOS miniaturization we developed an optical fingerprint reader with a resolution of 1600dpi. Further on, we will discuss the integration of organic photodiodes onto CMOS chips. A fluorescence sensor using OLEDs as excitation source and the CMOS backplane as driving and sensing platform will be described later on.

2 OLED microdisplays

Since every technology requires their individual process different advantages and drawbacks limit the combination of low power, high resolution and full color within one display device. To date the main approach to achieve a full color microdisplay is the combination of color filter and white OLEDs. The sub-pixel structuring of RGB and white OLEDs has already been shown but the transfer into mass production with a high yield and low cost is still a challenge. For the use case of virtual reality we developed a WUXGA microdisplay using the color filter and white OLED technology [1] (Figure 1).



Figure 1: Cross section of an white OLED on CMOS backplane with integrated RGB color filter

Very small pixel of less than 10µm can be achieved since the high resolution of lithography is used to generate the color filter and CMOS pixel pattern. The main drawback for this approach is the absorption of light within the color filter and thus very inefficient usage of white light to generate monochrome color. Because a high resolution and a high frame rate is typically required for full color displays the power consumption of these high resolution full color microdisplays is quite high. This high power consumption limits the use of these large displays in mobile applications. For these usage scenarios we developed a monochrome low resolution microdisplay for low content application like logistics, driving assistance and low information displays in general.[3] Since no color filter is needed and the use of a highly efficient (>50cd/A) green emitter with long lifetime, the display is very efficient in light generation compared to the color filter-white combination. The

shown content of the low power display changes with an adjustable frame rate of up to 25 fps enabling a reduced communication and circuitry requirement which leads to a final power consumption of 1 to 3 mW (Table 1).

Parameter	WUXGA	Ultra-low power
Resolution	1920 x 1200	304 x 256
Active Area	21.1 x 13.2 mm ²	3.65 x 3.07 mm ²
Display Diagonal	1"	0.19"
Frame Rate	up to 120 fps	up to 25 fps
Typ. / max current density backplane	25mA/cm ² max. 2A/cm ²	25mA/cm ² max. up to 1.3A/cm ²
Power	typ. 200mW (@300 cd/m²)	13mW
Application	VR	Information display
Reference	[1]	[3]

Table 1: Comparison of WUXGA and low power microdisplay

3 Organic devices on CMOS backplanes for sensing applications

The CMOS technology of silicon wafer foundries offer a variety of possible different devices miniaturized and integrated in the chip. The active matrix driving and communication of the display technology is only a very small fraction of the possible circuitry design. A photodiode sensitive in the visible is a standard component easily to be integrated in chips. Thus by combining the high resolution of OLED-microdisplays and the integration of photodiodes within the pixel of the display, an import feature can be added to the display functionality. We combined a microdisplay with a resolution of 800x600 with a pixel pitch of 16µm (with RGB sub pixel) with integrated photodiodes within every pixel cell. This combination enables the illumination of a directly attached finger to the display by the individual pixel as well as the reflection detection of the finger signature by the integrated photodiodes. Figure 2 shows the finger print-microdisplay combination with a picture of a formerly measured finger print in the display area. This finger print reader offers a resolution of 1600dpi whereas the resolution can be further improved by reducing the monochrome pixel size.



Figure 2: OLED-microdisplay with integrated photodiodes showing a measured finger print.

Currently the most common usage of organic semiconductors on CMOS technology are the microdisplays. But beside the organic LEDs the organic photodiodes (OPD) are an important group of devices. The OPD can be easily modified in view of absorption characteristic and offer the access to visible and nearinfrared wavelength. Thus we used our bidirectional display technology and modified the circuitry and the organic device to develop an imager with 800x600 resolution on basis of an OPD as light sensitive element.(Figure 3) To demonstrate the technical possibility of the OPD with CMOS technology the nearinfrared (NIR)-OPD was designed to be sensitive above 800 nm.[4] The cross section of the detector is very similar to the OLED microdisplay whereas the organic device was changed from OLED to OPD with modified circuitry within the CMOS. This OPD technology can be further improved towards sensitivity of the device above 1000nm but this strongly depends on the organic materials deposited on the wafer.



Figure 3: Comparison of measured picture of an NIR-OPD (left) and silicon (right) detector after 780nm VIS-cut off filter looking to trees in larger distance.

All presented devices in the publication so far had a

very high amount of small OLEDs/OPD pixel as well as many integrated photodiodes. Using the organic on silicon technology the development of sensors for process control or measuring concentration of substances in gaseous or liquid environment is a new research field with potentially high commercial impact due to the nearly unlimited amount of different possible sensors. We developed a fluorescence detection sensor to measure the amount of oxygen. For this purpose a fluorescent blue OLED were deposited onto a CMOS chip with integrated photodiodes, color filter and driving/sensing circuitry.(Figure 4)



Figure 4: Fluorescence sensor chip with different oxygen sensor materials in front.

The organic LED can be modulated with different pulse signals with frequencies between 100Hz up to 40kHz. The modulated blue OLEDs excites an oxygen sensitive phosphor material (yellowish sensor material in Figure 4). We tested a simplified sensor material which changes the luminescence decay time of the phosphor after excitation by the blue OLED depending on the amount of oxygen in the gaseous or liquid contact.[5]

4 Discussion/Conclusion

We presented different application scenarios of displayand sensor devices which are all based on the integration of organic semiconductors on CMOS backplane. Depending on the different key aspects of the devices the displays can be designed to offer a high resolution with full color as well as displays with a low screen diagonal, monochrome color and very low power consumption. By using this technology we demonstrated three different applications which represent a new technology in sensor developments combining the advantages of inorganic and organic semiconductors. Further on, the development of pixel sub-structuring technology for monochrome RGBemitter in displays will pave the way to further miniaturize the organic materials on sensors. In sum the organic devices combined with CMOS technology enable microdisplays as well as new sensor devices with increased functionality compared to pure silicon based devices.

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REFERENCES

- Philipp Wartenberg, Marina Buljan, Bernd Richter, Gunther Haas, Stephan Brenner, Mike Thieme, Uwe Vogel, Pablo Benitez, (2018), 40 - 5: Invited Paper: High Frame - Rate 1 "WUXGA OLED Microdisplay and Advanced Free - Form Optics for Ultra - Compact VR Headsets. SID Symposium Digest of Technical Papers, 49: 514-517. doi:10.1002/sdtp.12447
- [2] Uwe Vogel, Philipp Wartenberg, Bernd Richter, Stephan Brenner, Michael Thomschke, Karsten Fehse and Judith Baumgarten, (2015), 46 – 66 "SVGA Bidirectional OLED Microdisplay for near-toeye Projection", SID Proceedings, doi.org/10.1002/sdtp.10543
- [3] Vogel, Uwe, Beyer, Beatrice, Schober, Matthias, Wartenberg, Philipp, Brenner, Stephan, Bunk, Gerd, Ulbricht, Steffen, König, Peter and Richter, Bernd, (2017), 77 - 1: Invited Paper: Ultra - Iow Power OLED Microdisplay for Extended Battery Life in NTE Displays, SID Symposium Digest of Technical Papers, 48, doi: 10.1002/sdtp.11836
- [4] M. Jahnel, M. Thomschke, K. Fehse, U. Vogel, J.D. An, H. Park, K. Leo, C. Im (2015), 592 - 94 "Integration of near infrared and visible organic photodiodes on a complementary metal–oxide– semiconductor compatible backplane", Thin Solid Films
- [5] Torsten Mayr, Sergey M. Borisov, Tobias Abel, Barbara Enko, Kerstin Waich, Günter Mistlberger, and Ingo Klimant (2009), 81 – 6541 "Light Harvesting as a Simple and Versatile Way to Enhance Brightness of Luminescent Sensors", Analytical Chemistry