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# Exploring 3D Pixel Circuits for Small Pitch and High Brightness GaN Microdisplays.

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**Abstract**—Gallium nitride (GaN) based LEDs are a promising technology for microdisplays thanks to the brightness they can provide. However, they have not been widely adopted for this type of applications yet, partly due to the size and complexity of the associated driver circuits. In this paper, we demonstrate that despite the complexity of the driver circuits, a very small pixel pitch can be achieved thanks to CMOS 3D technology.

**Index Terms**—microdisplay, LED, 3D circuit, multi voltage, augmented reality.

## I. INTRODUCTION

Microdisplays are small dimensions display systems. Being of a small size, this kind of display is generally not intended for direct vision by the user, but is rather used in combination with an optical system magnifying the produced image. Due to their reduced size, microdisplays are a key component for head mounted displays such as augmented reality headsets [1], [2].

Like most of digital displays, microdisplays contain a pixel matrix, each pixel being individually controlled in order to generate an image. Two types of displays are particularly common, the lights processing ones, and the self-emitting ones. The light processing displays operate with an external light source, and depending on their pixels state, the light is stopped or allowed to pass through. Liquid crystals displays, and MEMS based displays belong to the light processing displays family. Light processing displays are out of the scope of this paper and will not be considered in the reported study, because of their limitations for the targeted applications. On the other hand, self-emitting displays' pixels are independent light sources, which are often LEDs on modern devices. To display an image, each pixel needs to be controlled in accordance to the input video signal. As display resolution increases, it becomes difficult to provide data through a dedicated link for each LED. Consequently, virtually all microdisplays use an active matrix. At any time, only one row of the matrix is selected and data provided to the columns only affect the selected row. Instead of leaving the unselected pixel off, each LED is connected to a driving circuit located underneath it. This circuit memorizes data when selected, and uses it to drive the LED when unselected.

Organic LEDs (OLED) have been used as light sources in self-emitting displays for more than a decade, and are still the most commonly used type of LEDs for this role [3]–[5]. OLED can provide a wide color gamut [6], offering the displays a good color rendering capability. OLED microdisplays can

reach very small pixel pitch thanks to their simple and compact pixel driving circuits. On the other hand, organic LEDs are known to suffer an important degradation during operation, especially when used under high current [7]–[9]. Although many mechanisms have been proposed to compensate for this degradation, they add complexity to the circuit. Furthermore, compensations are often done by providing more current to the damaged LEDs, accelerating their degradation. Consequently, despite the reported relatively high levels of brightness, OLED technology does not seem to be well suited for high brightness demanding applications (for example augmented reality devices can require a  $10^4$  -  $10^5$  cd/m<sup>2</sup> capable display to properly operate outdoor during a sunny day).

GaN based LEDs have been used in lighting applications for many years, and several microdisplays using these LEDs have been reported [10]–[13]. This LED technology suffers from a low maturity of manufacturing techniques at  $\mu\text{m}$  scale. Consequently, available micro-LEDs have more dispersed electrical characteristics and lower external quantum efficiency (EQE) than larger devices [14]. Because of GaN LEDs drawbacks, the simplest pixel driving schemes as sometimes found on OLED displays [15] don't seem suitable for GaN microLEDs which will require a more complex driving mechanism, thus limiting the ability to reach small pixel pitch. Thanks to its high brightness range (several order of magnitude higher than OLED), and the longer lifetime, GaN LED technology still gets lot of interest.

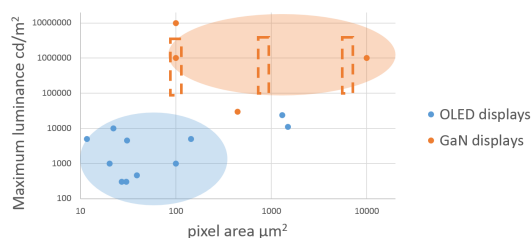


Fig. 1. OLED AND GaN displays performances.

The Figure 1 presents the brightness and pixels (or sub pixels for multicolor displays) area of displays reported the last few years. Dashed line rectangles represent displays for which only the pixel area is published and for which the brightness has been estimated based on the LED technology. This graph highlights the two different types of performances typically achieved with OLED and GaN, as well as the weaknesses of

these technologies (namely the limited brightness for OLED, and the relatively large minimum pixel area for GaN). In this paper we present a study on the possible reduction of GaN pixel pitch, using a 3D CMOS technology to implement the pixel driving circuitry.

## II. GAN DISPLAYS

### A. GaN LED

GaN based LEDs were reported to withstand high current density, and provide brightness as high as  $10^6$  cd/m<sup>2</sup> and  $10^7$  cd/m<sup>2</sup> [12]. It has been demonstrated that with the deposition of a GaN stack on the driving backplane, followed by the patterning of individual LEDs, pixel pitch as low as  $3\mu\text{m}$  is achievable [16]. Although to the best of our knowledge, no GaN oriented pixel driver with a matching pitch has been proposed.

The size of GaN LEDs has an influence on their characteristics, a given forward voltage results in higher current density through smaller LEDs. Under low current density, brightness-current density characteristic can be quite dispersed [17], and EQE is much lower for smaller LEDs. However the EQE gets similar for LEDs of all sizes, or slightly better for smaller ones under high current density [14], [18]. Consequently, in order to exploit GaN micro-LEDs at the best of their possibilities, they should be driven with a high current density. It shall be noticed, however, that GaN micro-LEDs current-voltage characteristic can be quite dispersed, one batch of 950 micro-LEDs has shown a current ranging over about two orders of magnitude for a forward voltage of 5V.

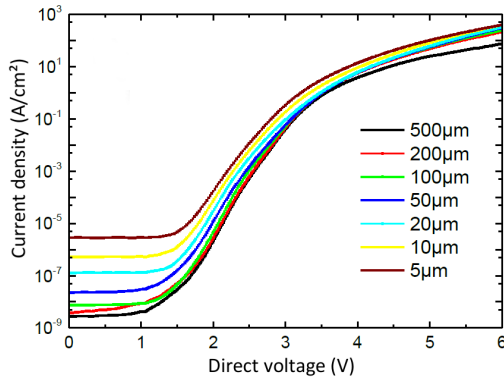


Fig. 2. Blue GaN LEDs current density versus applied voltage.

Figure 2 and Figure 3 are extracted from a previous work carried out in our institute [17]. They present the characteristics of GaN LEDs of different sizes. These characteristics are used in the reported study to determine the voltage and current to be provided by the proposed driving circuit, and the expected brightness.

### B. Driving scheme

Pixel driving circuits can power up a LED either by applying it a controlled voltage, or a controlled current. The current-voltage characteristic of the LED will determine the resulting

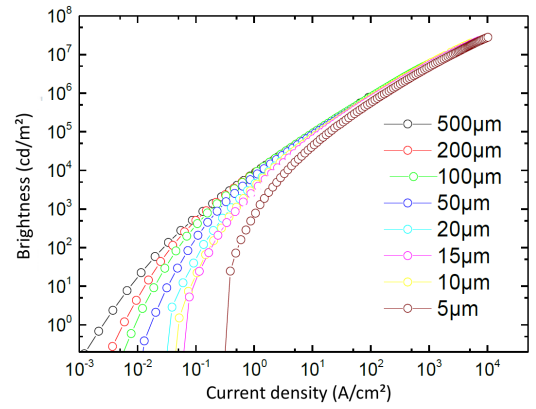


Fig. 3. Blue GaN LEDs brightness versus current density.

current through the LED in the first case, and the voltage on its terminals in the second case. The first solution known as voltage driving is commonly used in OLED displays, but would not allow a reliable control of a GaN micro-LED's brightness because of the characteristic dispersion mentioned above. Consequently the second solution known as current driving is the preferred one.

Good image quality requires both brightness uniformity across the pixel array, and a high enough color depth for each pixel (8 to 10 bits). As mentioned earlier, GaN micro-LEDs are not well suited for operation at low current density as EQE and LED to LED uniformity are quite poor under these conditions. In addition to the power efficiency reduction, the reduction of EQE at low current makes the brightness-current density a non-linear function even without taking dispersion into account. As a result, achieving different brightness levels for a pixel by generating different currents through the LED would not be a realistic solution.

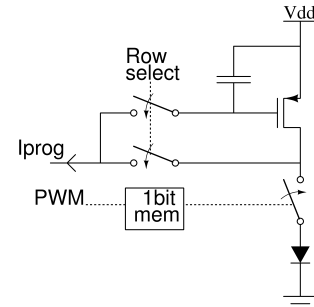


Fig. 4. PWM pixel circuit architecture.

Given the GaN microLEDs' specificities, a PWM driving scheme with a current source seems a good compromise between size and performances. Figure 4 illustrates the operation of this type of pixel. During the programming phase, the two programming switches (controlled by the Row select signal) are closed, and the current  $I_{prog}$  flows through the transistor connected as a diode. The gate source voltage corresponding to this current appears at the capacitor terminals. The programming switches are then blocked, and thanks to the capacitor



	2k x 2k eMagin's display [20]	Leti GaN display [12]	Display using the proposed pixel (with 6v VDD)
LED technology	OLED	GaN	GaN
Circuit technology	180nm CMOS	130nm CMOS	3D:28nm SOI 1.5V(GO2) + 28nm bulk 5V(GO3)
resolution	2048 x 2048 x RGBB	873 x 500	2048 x 2048 x 4 / 873 x 500
Emitting surface	19.05 x 19.05 mm <sup>2</sup>	8.73 x 5 mm <sup>2</sup>	18.68 x 18.68 mm <sup>2</sup> / 3.98 x 2.28mm <sup>2</sup>
Pixel pitch	4.65 μm	10 μm	4.56 μm
Brightness	5 000 cd/m <sup>2</sup>	10 <sup>6</sup> cd/m <sup>2</sup>	≈5x10 <sup>5</sup> cd/m <sup>2</sup>

TABLE I  
COMPARISON BETWEEN EXISTING DISPLAYS AND PROPOSED ONE.

between these particular pitches is linked to a fill factor reduction (assuming the pixel maintains a square shape).

#### IV. DISCUSSION

The Table I presents a comparison of the performances of three microdisplays: an OLED one available on the market, a published GaN one, and an hypothetical one using the proposed pixel circuit. For this comparison, the hypothetical display is powered with 6V, so 5V remain available for the LEDs which can absorb a current density of 10<sup>2</sup> A/cm<sup>2</sup> (as can be provided by the driving circuit) to reach a brightness of approximately 5x10<sup>5</sup> cd/m<sup>2</sup>. The proposed display would match the resolution of the existing GaN one in a surface about four times smaller, offering a pixel density comparable with the OLED display. The proposed display can reach a brightness one order of magnitude higher than the OLED display. Although it doesn't match the brightness of other GaN LED microdisplays, the proposed device exhibits a pixel pitch only achieved with OLED technology, while maintaining a brightness typical of GaN based microdisplays. However it shall be noticed that some constraints like the management of heat dissipation, or voltage drop in the matrix power supply, were not taken into account to estimate the hypothetical display's performances, consequences of these elements are currently under study.

#### V. CONCLUSION

We have shown that at a pixel level, the use of 3D technology makes it possible to build a PWM driving circuit with a pitch as small as what is typically obtained with simpler driving schemes. This pitch reduction is obtained by folding the circuit on two superimposed active layers, and using two MOS technologies with different operating voltages. The proposed solution tackles the tradeoff between having high brightness and low pixel density with GaN LEDs, or a high pixel density but insufficient brightness with OLEDs, which leads the way for many outdoor portable display applications.

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#### REFERENCES

- [1] H. Zervos, "Augmented Reality and Virtual Reality Smart Eyewear: Forecasts for the Next Decade," *SID Symposium Digest of Technical Papers*, vol. 47, no. 1, pp. 150–152, 2016.
- [2] G. Haas, "Microdisplays for Augmented and Virtual Reality," *SID Symposium Digest of Technical Papers*, vol. 49, no. 1, pp. 506–509, May 2018.
- [3] E. Naviasky *et al.*, "An 852/spl times/600 pixel OLED-on-silicon color microdisplay chip using CMOS sub-threshold-voltage-scaling current driver," in *2002 IEEE International Solid-State Circuits Conference. Digest of Technical Papers (Cat. No.02CH37315)*, vol. 1, Feb. 2002, pp. 436–437 vol.1.
- [4] V. Gohri *et al.*, "High Brightness Green OLED Microdisplay with High Resolution and Low Power Consumption," *SID Symposium Digest of Technical Papers*, 2011.
- [5] U. Vogel *et al.*, "OLED Microdisplays — Enabling Advanced Near-to-Eye Displays, Sensors, and Beyond," *SID Symposium Digest of Technical Papers*, vol. 47, no. 1, pp. 703–706, 2016.
- [6] S. Hosoumi *et al.*, "Ultra-wide Color Gamut OLED Display using a Deep-red Phosphorescent Device with High Efficiency, Long Life, Thermal Stability, and Absolute BT.2020 Red Chromaticity," *SID Symposium Digest of Technical Papers*, vol. 48, no. 1, pp. 13–16, 2017.
- [7] J. S. Price *et al.*, "High Thermal Stability OLEDs," *SID Symposium Digest of Technical Papers*, vol. 48, no. 1, pp. 565–565, 2017.
- [8] D. Antonio-Torres *et al.*, "Modelling of a Compensation Scheme for OLED Degradation," *SID Symposium Digest of Technical Papers*, vol. 35, no. 1, pp. 1124–1127, 2004.
- [9] K.-Y. Lee *et al.*, "Realizing a New Pixel Circuit Design for Alleviating OLED Degradation in a 2.4 Inch AMOLED Panel," *SID Symposium Digest of Technical Papers*, vol. 42, no. 1, pp. 1173–1176, 2011.
- [10] Z. J. Liu *et al.*, "360 PPI Flip-Chip Mounted Active Matrix Addressable Light Emitting Diode on Silicon (LEDoS) Micro-Displays," *Journal of Display Technology*, vol. 9, no. 8, pp. 678–682, Aug. 2013.
- [11] J. Herrnsdorf *et al.*, "Active-Matrix GaN Micro Light-Emitting Diode Display With Unprecedented Brightness," *IEEE Transactions on Electron Devices*, vol. 62, no. 6, pp. 1918–1925, Jun. 2015.
- [12] F. Templier *et al.*, "GaN-based Emissive Microdisplays: A Very Promising Technology for Compact, Ultra-high Brightness Display Systems," *SID Symposium Digest of Technical Papers*, vol. 47, no. 1, pp. 1013–1016, 2016.
- [13] X. Li *et al.*, "Design and Characterization of Active Matrix LED Microdisplays With Embedded Visible Light Communication Transmitter," *Journal of Lightwave Technology*, vol. 34, no. 14, pp. 3449–3457, Jul. 2016.
- [14] A. Daami *et al.*, "Electro-optical size-dependence investigation in GaN micro-LED devices," *SID Symposium Digest of Technical Papers*, vol. 49, no. 1, pp. 790–793, 2018.
- [15] M. Shiokawa *et al.*, "A 1058 ppi 8k4k OLED Display using a Top-Gate Self-Aligned CAAC Oxide Semiconductor FET," *SID Symposium Digest of Technical Papers*, vol. 47, no. 1, pp. 1209–1212, 2016.
- [16] F. Templier *et al.*, "A Novel Process for Fabricating High-Resolution and Very Small Pixel-pitch GaN LED Microdisplays," *SID Symposium Digest of Technical Papers*, pp. 268–271, 2017.
- [17] F. Olivier, "Etude des caractéristiques électro-optiques de micro-LED GaN pour application aux micro-écrans haute luminance," Theses, Université Grenoble Alpes, Mar. 2018.
- [18] F. Olivier *et al.*, "Influence of size-reduction on the performances of GaN-based micro-LEDs for display application," *Journal of Luminescence*, vol. 191, pp. 112–116, Nov. 2017.
- [19] J. Jourdon *et al.*, "Hybrid bonding for 3d stacked image sensors: impact of pitch shrinkage on interconnect robustness," in *2018 IEEE International Electron Devices Meeting (IEDM)*, Dec. 2018, pp. 7.3.1–7.3.4.
- [20] A. Ghosh *et al.*, "Ultra-High-Brightness 2k x 2k Full-Color OLED Microdisplay Using Direct Patterning of OLED Emitters," *SID Symposium Digest of Technical Papers*, vol. 48, no. 1, pp. 226–229, 2017.