Building Active matrix MicroLED displays By Additive Manufacturing (BAMBAM) – Paving the way to a sustainable fine pitch video wall

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ABSTRACT

The BAMBAM project aims to showcase the viability of an active matrix µLED display through the mass transfer on a µPackage of 3 blue NanoWire µLEDs and a pixel driver, establishing connectivity by employing silver-based wire printing on the dies and PCB interconnections. Furthermore, the project focuses on incorporating a color conversion module, utilizing patterned cavities and Red and Green Quantum Dot inks for printing. This integrated approach offers a sustainable digital pixel solution, enabling the development of high-resolution display.

1 BamBam Project

1.1 Fine Pitch Video Wall

The BamBam project, driven by a consortium with University of Stuttgart, XDISPLAY, XCELEPRINT, QUSTOMDOT, BARCO, ALEDIA & XTPL, is dedicated to addressing the fine pitch Video Wall (VW) market segment. Recognizing the potential of the additive technologies for market expansion and industrialization in Europe, this consortium has been established with partners offering a large panel of technologies, the assembly of which will expose disruptive & sustainable displays.

1.2 BamBam Pixel

The key technical differentiator of the BamBam pixel is the micro printing solution proposed by XTPL [1] and the University of Stuttgart. It offers the opportunity to achieve very narrow metal lines, down to the µm in width, but also to have a very accurate positioning of the lines with respect to the structures they are interconnecting (+/-2µm). In comparison with wire bonding rules (wire length ~ 1.5x die thickness & min. pad size ~40µm), wire printing releases connecting constraints by at least half an order of magnitude, paving the way to smaller to packages since pixel package size comes mainly from die position, printing accuracy and die size. Based on this key innovation, the consortium has designed an RGB Digital Pixel based on the following innovative heterogenous integration (Fig 1A) : on a polyimide Flex µPackage, XCELEPRINT mass transfers by stamp 3 small blue µLEDs (30x70µm²) (even better if it is Aledia NanoWire (NW) µLed with very high efficiency) and one µIC low power pixel driver (50x90µm²) designed by XDISPLAY. The positioning accuracy is very good (+/-1µm), and those dies are connected by silver-based wire printing. With such an integration, connecting very small µLed on a tiny area is possible. Comparatively, it overcomes the main drawback of the Chip On Board (COB) pixels which are limited by the Pick and Place (P&P) capability (~70µm with 2 pads Flip Chip COB, ~150µm with 4 pads Flip Chip COB)[2]. Wire printing provides similar design tolerances as photolithography on glass, which is the standard for high resolution display manufacturing, but it can be used on PCB. In comparison with Chip On Glass (COG), which is limited by the capability to connect to the backside, BamBam integration on PCB offers the capability of seamless tiles assembly. Actually, BamBam takes the best of the SMD packaging integration (easy P&P, test, sorting) and enables small, thus low cost µLed as regularly used in COG. Associated to a CMOS driver operating the LED in pulse width modulation mode, it overcomes the driving limitation of the TFT technology like IR drop, color shift with analog current driving & non-uniformity due to Vth variation [3]. After mass transfer and printing of metal lines, cavities are patterned with a black matrix on top and filled by printing with Green Qdot inks. This Color Conversion Module (CCM) integration is optimal to get broader color gamut (narrow and tunable wavelength) and higher efficiency (no diffuser for color uniformity in angle as usually done on SMD)) with an easy FarField management (Fig 1B). Finally the µPackage panel is diced into 325x235µm² pixel which is compatible for pick and place on the fine pitch flexible tile. With a such approach, pitch has been reduced easily because backside layout is strongly simplified with Active-Matrix driving. No more issue with the tradeoff driver density and scan speed (64 or 128 scans at 500µm) and the very short LSB (~10ns) impacting the display dynamics. Hence, reducing the size down to

~300µm by considering all additive solutions: electrical, optical & assembly enables to propose an innovative printed µSMD Digital Pixel.

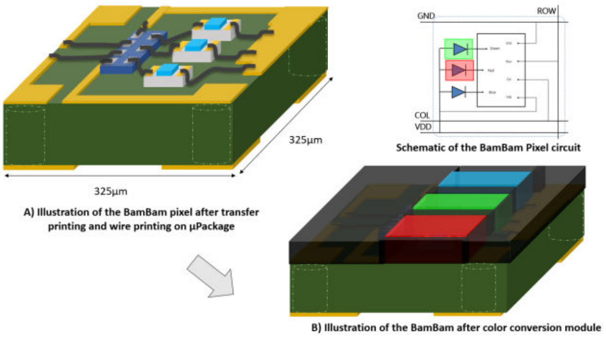


Figure 1 : Illustration of the BamBam pixel

1.3 BamBam VideoWall Tile specification

With the BamBam pixel, the consortium designs and manufactures a VW tile with the following specifications:

- Pitch equal to 390µm (home theater videowall)
- Flexible substrate,
- RGB active matrix,
- 100% REC2020,
- Brightness 1200nits
- Power Consumption < 200W/m²
- Lifetime L50 100kh
- High contrast 1:10k

Simultaneously, in light of the pressing issue of climate change, it has become imperative to prioritize the development of sustainable solutions. The printed technologies enable us to reach this objectives as explained in [4] (much better than LCD & OLED).

2 Preliminary BamBam Results

This section describes the preliminary results of the BamBam project.

2.1 BamBam Packaged Digital Pixel Concept

Before moving forward to the final BamBam pixel, the consortium debugged the packaged digital pixel (Fig 2) and the test/sorting strategy (D) with an Aledia R&D RGB µLed and a pixel driver compatible with wire bonding.

Now, similar experiments are in progress on glass with the XDC driver and by switching to wire printing (F).

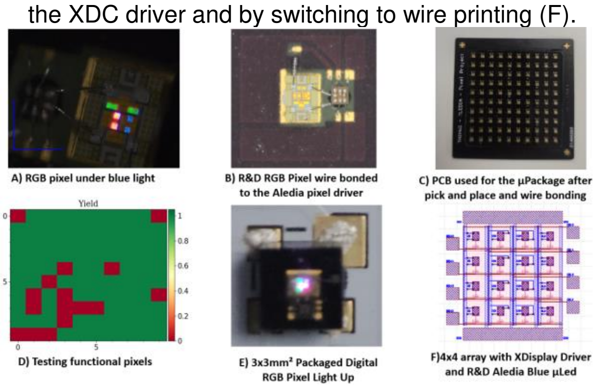
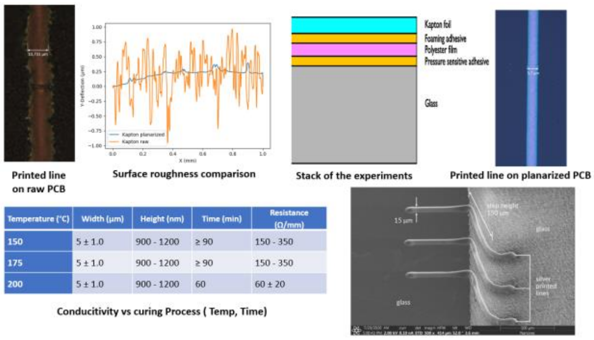


Figure 2 : Validation of the Package Digital Pixel

2.2 Wire printing on Glass, Polyimide and PCB

In parallel, USTUTT tested the silver-based wire printing on different kinds of substrates. Glass and Polyimide gave good results whereas standard PCB showed not optimal results (Figure 3). Moreover, the impact of the ink curing (temperature and time) on conductivity has been analyzed. Printing over 90° step has been done as well with success. It means that the BamBam integration based on a wire printing on 30µm thickness die on a polyimide µpackage should work.



Temperature (°C)	Width (µm)	Height (nm)	Time (min)	Resistance (Ω/mm)
150	5 ± 1.0	900 - 1200	≥ 90	150 - 350
175	5 ± 1.0	900 - 1200	≥ 90	150 - 350
200	5 ± 1.0	900 - 1200	60	60 ± 20

Conducitivity vs curing Process (Temp, Time)

Figure 3 : Silver based wire printing on Polyimide.

2.3 Nanowire µLed by Aledia

Aledia is developing 3D µLed based on epitaxially grown blue GaN Nanowire µ-LED on Si-wafer. When compared to existing products (LCDs, OLEDS, LCOS), this unique technology offers added energy efficiency (longer battery life) and higher brightness (outdoors readability) especially below ~20µm (Figure 4). The BamBam blue µLed is designed with 2 front side pads and aluminum as mirror at the bottom of the wire and pad compatible with wire printing rules. The pitch on the wafer will be 90x50µm to make it compatible with mass transfer printing, After a blade dicing with 20µm of dicing street (without impact on NW and the yield!) the µLed size will be around 70x30µm². The active area will be around 30x40 µm²: 48 Nanowire µLeds.

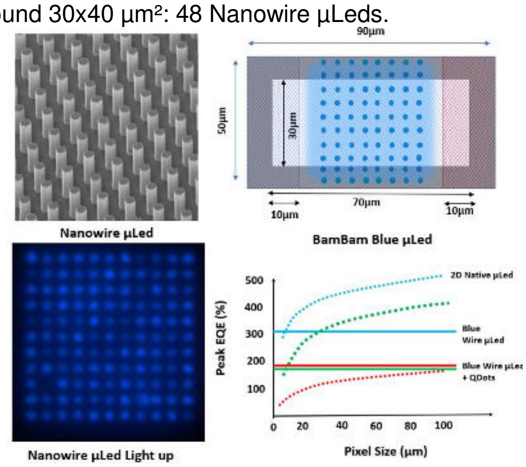


Figure 4 : BamBam Blue NW µLed

2.4 RGB Light up

Based on the solutions described in 2.2, the consortium connected R&D Aledia µLed by side wall isolation and silver-based wire printing. Although this experiment was successful (Figure 5), it revealed that a gold pad is required to avoid oxidation of the surface. A preliminary burn at 20V is required for light up. Contrary to the wire bond, printed wire cannot mechanically enter the pad and a perfect pad surface is required.

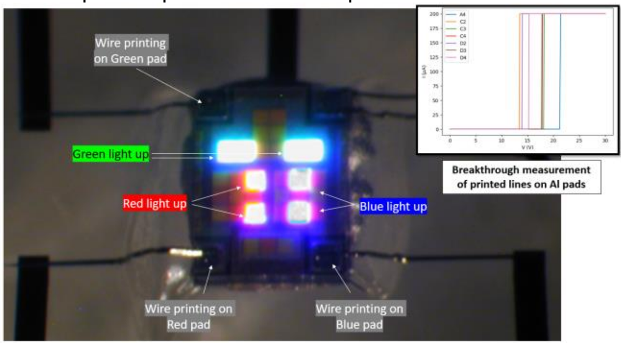


Figure 5 : RGB Light up after wire printing

2.5 Micro Transfer Printing of the Pixel Driver

More than 15 years after its introduction, moving microLED with elastomer stamps is still one of the best way for mass transfer. Combining accuracy and tolerance for real-world materials (+/- 1µm), micro transfer printing allows transferring millions of devices at a time [5]. The mass transfer process of the µIC pixel driver utilizes the Anchors and Tethers method. This innovative technique involves etching below the die to release it using a sacrificial layer. The die is then attached to the wafer via anchors and tethers, and upon applying stamp pressure, the tethers are broken, allowing the release of the dies as illustrated in Figure 6.

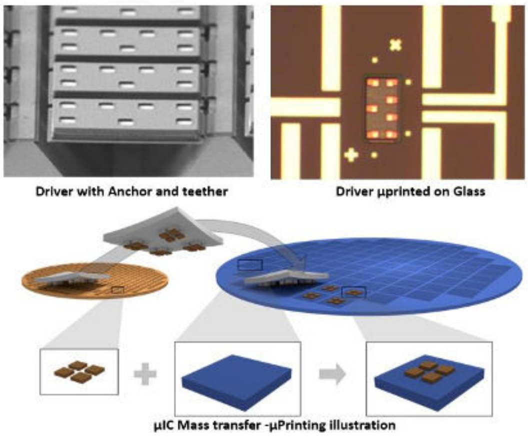


Figure 6 : Pixel driver µprinting on glass

2.6 Micro Transfer Printing of the µLed

For the µLed printing, the consortium uses the Aledia expertise on ultimate grinding (below 50µm of thickness) and advanced singulation. Experiments are ongoing on dummies which have the same size than the final µled (pitch of 50x90µm² and size of 30x70µm²).

2.7 Quantum Dot Ink Formulation by QustomDot

InP-based Quantum Dots (QDs) emerged as one of the best optoelectronic ROHS compliant materials that combine high absorption coefficients with narrow and size-tunable emission properties and low toxicity vs Cd/Pb based QDs. It makes this material the only sustainable one for display industry [6]. The purpose at this stage, is to develop a QD ink (green and red) which is compatible with the XTPL printing process.

	Green	Red
Emission Peak (nm)	520	630
FWHM (nm)	45	47
PLQY (%)	80	75

QD's optical specs

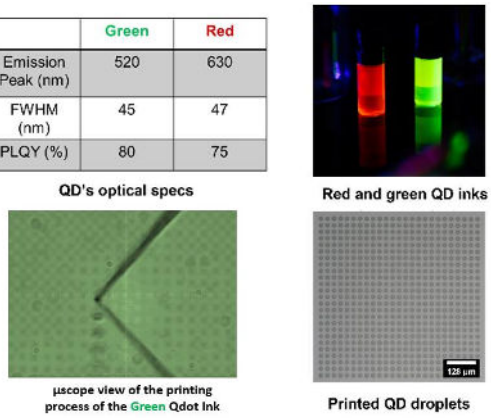


Figure 7 : Red and Green Ink Formulation

After adjusting ink formulation as well as QD loading, perfect ink compositions were identified. Main success criteria are the robustness (no nozzle clocking) the minimal dot size (4µm!) and the repeatability (Figure 7).

2.8 Cavities filling with Qdot ink

To test the cavity filling with Qdot, Aledia processed 135x40µm² cavities matrix on glass. By using the red and green inks compatible with the XTPL Delta Printing System, some printing trials were performed. As illustrated hereafter, printing enables a perfect control of the Qdot layer thickness in the cavity, which is very important for future optimization when adding blue light filters on top. (Conversion efficiency and Light Extraction Efficiency, Color Gamut). (Figure 8)

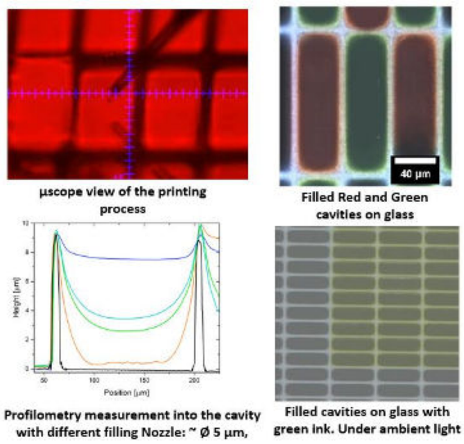


Figure 8 : Red and Green Cavity Filling

2.9 µPackage Design and Heterogenous integration

The design of the 325x325µm² µPackage for the

BamBam digital RGB pixel is mainly based on the printing of wires, dies printing solution, which offer the opportunity to connect dies in a very tiny area. However there are some constraints:

- Geometric magnification compatibility between µdriver pitch, µLed pitch and µpackage pitch for transfer printing.
- Wire printing accuracy & printing sequence (+/-2µm)
- µPackage interconnection width and spacing (25µm)
- Mass transfer and die attach resolution (+/-2µm)
- Cavity patterning and QD ink printing constraints

Based on those constraints the design has been defined as illustrated below (Figure 9).

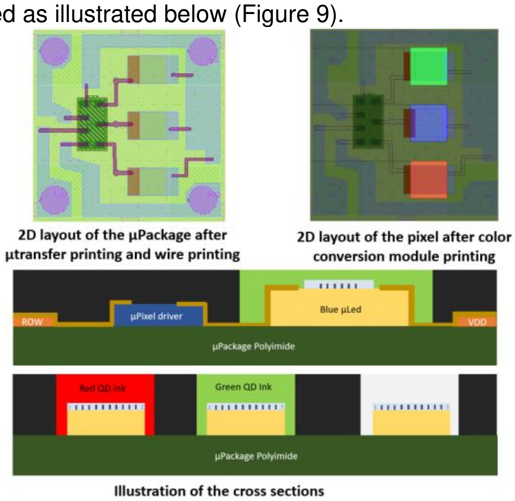


Figure 9 : Layout and stack of the BamBam pixel

2.10 Pixel driving and Demo

The XDisplay Pixel Engine™(PxE) is designed to drive the RGB pixel [7]: Each pixel µIC drives three µLEDs as three sub-pixels. Row, Column, Power, and Ground are connected to the µIC and µpackage Pad. There are 16 bits per color (14 bits PWM, 2 bits current selector).

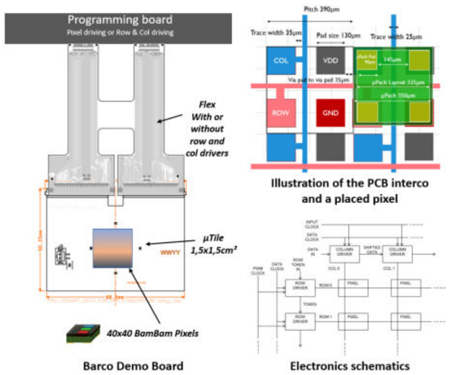


Figure 10 : Electronics and Demo

Moreover, the advanced features (multi driving current, Pulse Width Modulation (PWM) protocol and low power design) enable excellent display driving without limitation of the TFT. In addition, printable µIC row & column drivers are designed to reduce display I/O count. Column drivers demultiplex data. Row drivers provide clocking for data writing in the pixel and PWM.

Based on this complete driver's framework and the BamBam pixel, the consortium has designed a simple µtile (40x40 pixels and a size of 1,5x1,5cm²) connected by Flex to a R&D Barco test board (Figure 10). This board will be able to drive the tile with and without row and col drivers. With preliminary binning, since the test, sorting will be done at package level, the pixel-to-pixel calibration (measuring brightness and color of every pixel, calculating calibration factor table) and the optimization will be simplified (in comparison with COG approach where redundancy is required for yield and color uniformity). Then, Barco will perform a complete set of display optimization and test beginning of 2024 to analyze the BamBam pixel capabilities deeply.

3 Conclusion

OLED and LCD industries took time (>10 years) to propose great displays by compensating their respective weakness (high power consumption, screen burn-in). To make the difference, µled industry shall expose pixel with a great high-end values and key differentiators like high color gamut, high efficiency & sustainable and low-cost integration. By proposing this innovating µSDM approach by printing with the help of QD and Aledia NW µled, the BamBam project will reach this objective.

4 Acknowledgment

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