Improvement of MicroLED Efficiency Through Optimization of Electrode Area and Device Geometry

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ABSTRACT

MicroLEDs offer the potential to develop a variety of displays in a number of new formats with exceptional performance with luminance, efficiency, and color gamut unavailable in competing technologies. In all microLED display configurations (transparent displays, large-format mass-transfer displays, and microdisplay) there is a strong interest in the isolation of the emissive area to enhance pixel definition. While this is often achieved through mesa etching, this approach has a significant impact on device efficiency and especially problematic at smaller pixel sizes. This work will introduce several strategies including ion implantation and bias control for achieving small LED emitting areas while retaining high device efficiency.

1 Introduction

Both microLED microdisplays and large area direct view displays have been using increasingly scaled LED pixels to achieve high resolution and low material use and cost. Using active matrix co-integration strategies including the use of thin film transistors, co-integrated silicon devices, and microIC chiplets, a high level of scaling and control has been demonstrated by a number of groups.[1] The extraordinary luminance achievable using LEDs (20-50M nits+) at least in theory, allows for extremely small pixel elements; for many display formats these elements can be considered a the 1-10 micron scale, but it has been shown that many of the strategies traditionally proposed for reducing the emissive area such as fabrication of mesas can lead to limitations in the device efficiency due to recombination regions associated with damage to the LED sidewalls. [2]

There are three major display formats that are in development for microLEDs – chiplet/mass-transfer based technologies, microdisplays, and transparent direct-view displays. In all three formats there is an advantage to reduce the pixel size. In a chiplet-based display, the size of the chiplets affects the efficiency of the overall system and the system cost. In a microdisplay, high resolution and fill factor require small chiplets for high system-level performace. Finally, in direct-view transparent displays, the extremely low fill factor required for system transparency requires a small pixel size. All of these considerations are essentially independent of the active matrix used to control the current drive

2 Mechanisms impacting current and light spread

The effective pixel size is a function of several factors, but is in many cases dominated by current spread in the injection regions of the LED. The high carrier mobility in GaN especially leads to a long diffusion length, allowing for significant current spread before the introduction of the charge into the recombination region of the device. While electrical crosstalk and current spread is important, optical spread (e.g. through waveguiding in the LED) is also an additional important factor that needs to be considered when decreasing pixel size is to be considered.

3 Restricted injection area

One of the simplest strategies for reducing the effective pixel size is to reduce the lateral dimensions of the injecting contact. This has a number of impacts on device efficiency discussed in more detail in [2] and [3], but a reduction in the injection area allows for a significantly smaller pixel without a significant impact on efficiency.

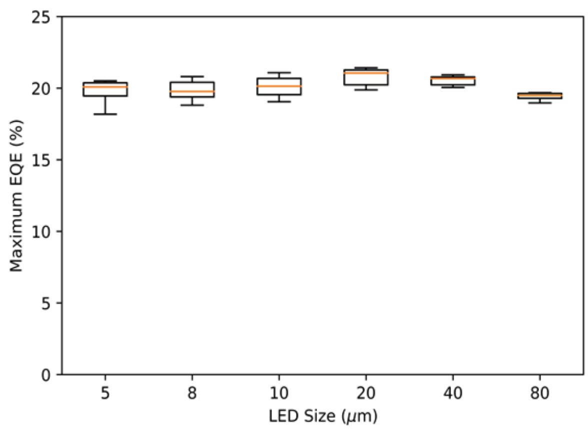

Figure 1: The efficiency vs. pixel size for a mesa-free LED display structure

. This approach does have its limitations; in particular the LED optical crosstalk issue present in many displays remains entirely unaddressed.

4 High bias for drive

Many (if not most) microLED displays are driven using a PWM drive approach at a relatively high bias. This drive approach offers a number of advantages – the LED can be driven at a level close to the peak efficiency,[5] and PWM offers a linearity in luminance which is not available through voltage or current drive scaling, which are highly nonlinear. There is an additional advantage, however, to driving the LEDs at a relatively high bias – the larger bias allows for charge to move faster vertically, delivering the charge to the recombination layer faster and permitting less lateral spread. This approach leads to a reduction in the lateral current spread in the LED pixel elements, especially at a small size.

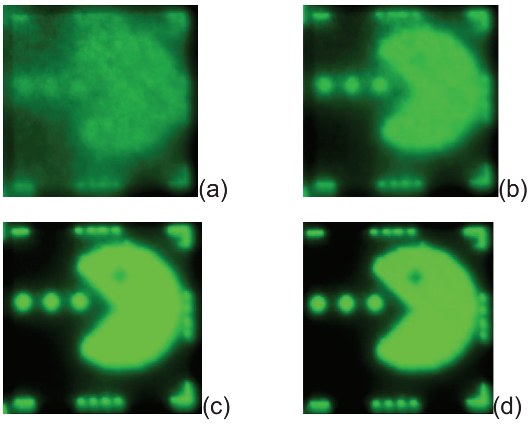

Figure 2: A test structure driven under progressively increasing applied bias (a-d). At higher bias less lateral spread is observed, since the charge vertical drift overcomes the lateral diffusion in the structure

5 Implantation for deactivation of dopants in transport layers

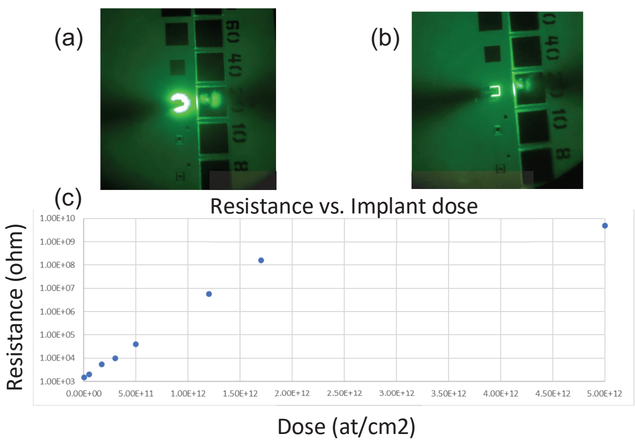

Figure 3: (a) Control wafer (no N implant) (b) Implanted for isolation (c) dose vs. resistance

It is possible to defeat lateral diffusion by increasing the resistivity of the top contact layers. By implanting nitrogen, the resistivity of GaN can be increased substantially, leading to a decrease in the diffusion length. This approach permits the confinement of the carriers in the LED device without the creation of a recombination region that would otherwise impact the overall LED efficiency. Figure 3 shows the results from this approach.

Other groups have recently also demonstrated isolation using ion implantation with similar results; Xu, et al. [6] show excellent performance and high temperature stability using F implantation, and Liu et al. [7] demonstrate a surface passivation effect upon N implantation, confirming the observed effect.

6 Conclusions

MicroLEDs offer a number of advantages over other direct and indirect view displays due to their high luminance, efficiency, and lifetime. Many of the display formats envisioned for microLEDs are advantaged by small pixel sizes for performance and cost reasons, and a number of strategies for reducing the emissive pixel area have been proposed. In this work we discussed three strategies for reduction in the electrical pixel emissive area - the use of a restricted injection area, driving the LED at the peak current density, and the use of ion implantation to deactivate the doping of the transport layers. Each of these three approaches allows for the reduction in emissive region without a dramatic loss in efficiency and represents a useful tool for achieving small pixel size while retaining the favorable characteristics of microLEDs..While these three approaches can decrease the emitting area electrically, additional work is required to co-integrate these techniques with strategies for optical control of the microLED devices and emitting area. These devices offer a range of functionality for both display and non-display applications.

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