High Performance Micrometer Size LEDs on 8'' Si Wafers

Ivan-Christophe Robin[1], Yoann Malier[1], Romain Cipro[1], Zaiyuan Ren[1], Pierre Tchoulfian[1], Philippe Gilet[1]

Ivan-christophe.robin@aledia.com
[1]ALEDIA SAS, Parc Sud Galaxie, 10 rue des Méridiens
38130 ECHIROLLES FRANCE
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ABSTRACT

One of the microLED display major challenges is to drastically reduce the cost, for instance, by reducing as much as possible the microLED size. Usually, planar LEDs efficiency drops with chip downsizing. Aledia has developed a nanowire (NW) microLED technology on 8'' Si wafers which keeps the same efficiency for <2µm size devices containing only 1NW as for larger devices containing up to few hundreds of NWs. We present in this paper a 1.2µm large µLEDs with 14% External Quantum Efficiency (EQE) at 10 A/cm^2. This technology provides similar efficiency as well as electro-optical parameters (I-V and Emission Spectra) whatever the µLED size. Those results show that our technology can allow the manufacturing of micron size µLEDs on a Si platform without experiencing a loss of efficiency with size reduction, allowing cost competitive and energy efficient direct-view displays.

1 Introduction

2D µLEDs have a problem of EQE decrease with the size reduction [1],[2]. To overcome this issue, the passivation of GaN side walls after etching was optimized [3].

In this paper, we present core shell nanowire (NWs) LEDs grown on 8'' Si substrates. In order to obtain a µLED from those NWs, there is no need to etch through the quantum wells (QWs) of the LED structure. Thus, there is no need of passivation in order to keep good efficiency. µLEDs' EQE obtained by processing those NWs is independent of the size of the µLED. This size independent EQE and the possibility of growing the NWs on 8'' or even 12'' Si substrates is of great interest for direct view display applications.

2 Nanowire structure

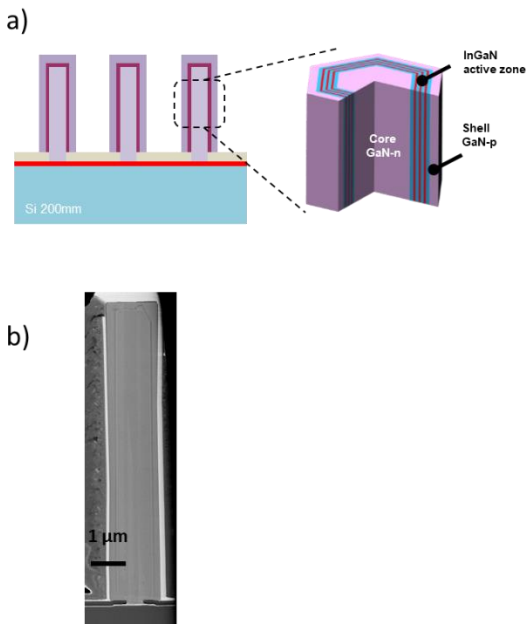

Figure 1: a) NWs structure b) NW cut observation by TEM

Figure 1 presents a) the core shell NW structure obtained by MOCVD growth on 8'' Si substrates and b) a TEM observation of our NWs. With our technology, the NWs are grown on standard (001) Si 725µm thick Si substrates.

What is seen is that our NW is free of defect like threading dislocation especially in the active region compared to a µLED obtained using 2D material. This ends up with a perfect active area as compared with 2D based µLEDs, which experiences "bulk defect" such as threading dislocation [3] concurrently with surface defect that occur during the definition of the µLEDs with patterning of a 2D epilayer [1],[2].

Indeed, the active region is warped around the NWs. The NWs are typically 1.2µm in diameter and in order to form a µLED with those NWs, we developed a process to connect the p-GaN shell of the NWs with a p-contact and to connect the n-GaN core from the Si side.

3 Results

From the NWs presented in Figure 1, we processed

µLEDs containing different numbers of NWs, from 1 NW to 256 NWs i.e. from a 1.2 X 1.2 µm² size µLed to 80 x 80 µm² size.

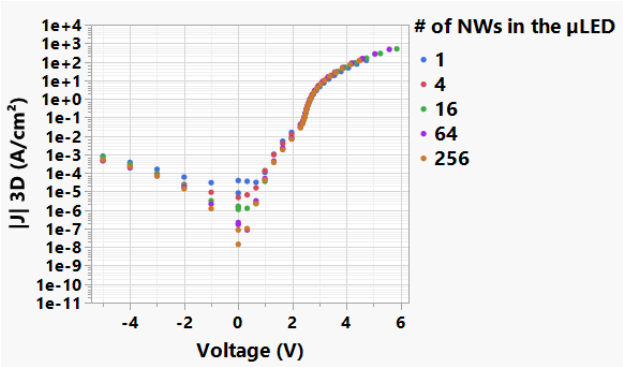

Figure 2: Current density in the 3D NW LEDs (J 3D) vs voltage for µLEDs formed with 1, 4, 16, 64 or 256 NWs

Figure 2 shows the current density in the 3D NW LEDs (J3D) vs voltage for µLEDs formed with 1, 4, 16, 64 or 256 NWs. The µLEDs were formed using the NWs of the same wafer at random places.

What is seen is that all the curves perfectly superimpose, showing that there is no dependence of the electrical properties' vs the size of the µLEDs.

Low level of reverse leakage, good rectifying behavior and V@10 A/cm2 around 3V can be observed.

With such an approach a 1 NW µLED is 1.2µm large.

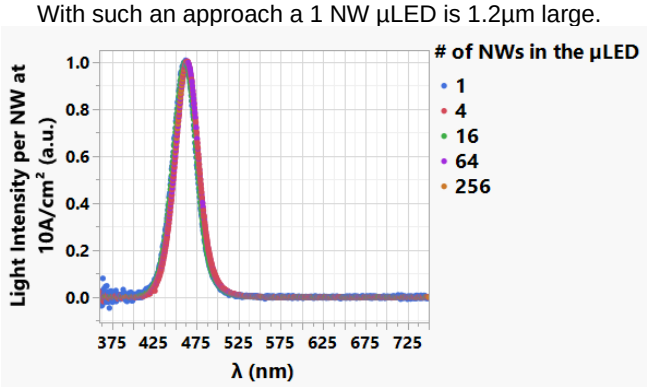

Figure 3: Electroluminescence spectra at 10A/cm2 normalized by the number of NWs in the µLED for µLEDs containing between 1 NW and 256 NWs

Figure 3 presents the Electroluminescence spectra at 10 A/cm2 normalized by the number of NWs in the µLED for µLEDs containing between 1 NW and 256 NWs. The µLEDs were formed using the NWs of the same wafer at random places.

It is seen that the spectra are independent of the number of NWs, showing no dependence of the optical properties of the single NWs vs the number of NWs in the µLEDs.

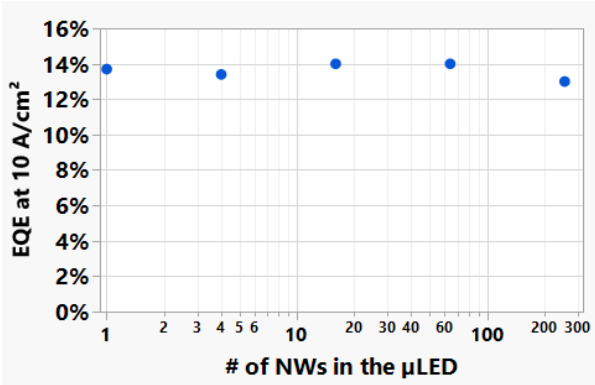

Figure 4: EQE of µLEDs vs the number of NWs in the µLEDs. The µLEDs were formed from NWs grown on the same wafer

Figure 4 presents the EQE at 10A/cm^2 of the µLEDs vs the number of NWs in the µLEDs for µLEDs formed from the NWs grown on the same wafer. It is clearly seen that the measured EQE doesn't depend on the number of NWs in the µLED. The maximum of the efficiency curve with our NWs is at 0.5A/cm^2, which is a pretty low value compared to 2D LEDs. This is a clear advantage for the use of our µLEDs in direct view displays in which the µLEDs are going to be operated at low current density.

The measurements were done at wafer level i.e. without any Light extraction enhancement such as dome, texturization. The extraction was not optimized and is estimated at 40% maximum. Those results are highly reproductible and homogenous on a 200 mm wafer.
Aledia is also working on scaling up this process on 300 mm wafers [5] , and have shown the first full 300mm processed LEDs since late 2020.

4 Conclusions

Results were presented showing the capability of Aledia NWs grown on 200 mm Si substrates to reduce the emission size of µLED devices down to 1.2µm size without any loss of efficiency. Aledia developed a µLED process compatible with manufacturing in a foundry (back end of the line) and is also working on a high throughput low cost transfer process, opening the way to consumer cost compatible direct view µLED displays.

References

[1] Olivier, F. et al. "Influence of size-reduction on the performances of GaN-based micro-LEDs for display application." *J. Lumin.* 191, 112‑116 (2017).

[2] Smith, J. M. et al. "Comparison of size-dependent characteristics of blue and green InGaN microLEDs down to 1 µm diameter." *Appl. Phys. Lett.* 116, 071102 (2020).

[3] Mihyang Sheen et al., "Highly efficient blue InGaN nanoscale light-emitting diodes," Nature, Vol. 608, pp. 56 (2022).

[4] Heng Li et al. "Three dimensional characterization

of GaN-based light emitting diode grown on patterned sapphire substrate by confocal Raman and photoluminescence Spectromicroscopy" Nature Scientific report 7:45519 | DOI: 10.1038

[5] Philippe Gilet "Moving microLED manufacturing to 300mm wafer size" International Micro/Mini LED Display Conference – Touch Taiwan 2022 Oral Presentation