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InGaN/GaN µLEDS for display applications Optical and electrical characteristics spread comprehension

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Abstract

Electroluminescence and photoluminescence cartographies carried out on GaN-based µLEDs for display applications show different optical spread behaviours. We show using a simple SPICE model and Monte Carlo simulations that electroluminescence high dispersion can be related to a variation of carrier injection due a non-uniformity of the contact resistance of processed µLEDs.

1. Introduction

Augmented and virtual reality tools have seen a growing interest in this last decade. This attentiveness to these devices has implied the need of high brightness and high resolution arrays, which has drawn important research on GaN based µLEDs [1] [2] [3]. Many results have reported GaN microdisplays with different pixel pitches and matrix resolutions [4][5]. In this paper we report an electro-optical study on our previously reported emissive microdisplay [6] showing the importance of electric contacts on the uniformity of light power output. We show by a Monte Carlo SPICE based simulation that optical power dispersion observed on our microdisplay is mainly due to a variation of the contact resistance on µLEDs.

2. Results

Process fabrication

Our emissive arrays of 873x500 pixels are fabricated with a self-aligned process and a damascene metallization on commercial 4'' epitaxial InGaN/GaN wafers grown on non-patterned c-plane sapphire substrates by MOCVD. A complete description of the process is found in [7].

Experimental measurements

Figure 1 (left side) shows the electroluminescence optical photograph taken on 2500 pixels, corresponding to an area of 500x500 µm², from our µ-display working under a bias of 4.5V. We easily remark a rather high spreading on light intensity between the µLEDs. On the other hand, the micro-photoluminescence intensity map at λ=440 nm represented on the right side of figure 1, and realized on a 400x400 µm² area of the same epitaxy shows a good signal uniformity.

We have also carried out unitary light-current-voltage measurements on 300 µLEDs, coming from the same emissive micro-array and having a diameter of 8µm in order to understand this electroluminescence dispersion.

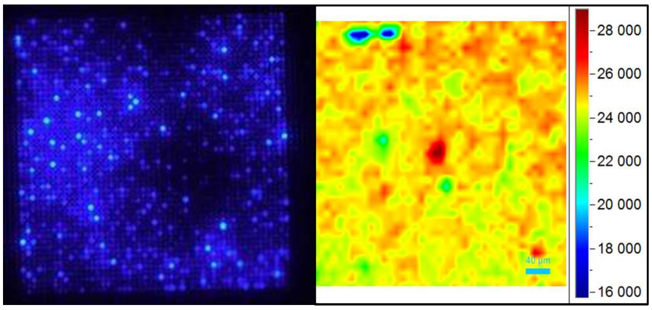

Fig. 1 Optical photograph of 50x50 pixels biased at 4.5V (left), photoluminescence intensity map at λ=440nm on a 400x400 µm² zone.

We plot in figure 2 the optical power versus the electric current taken at a voltage of 4.5V for all measured µLEDs. We perceive on this figure a proportionality of optical power versus injected current. Furthermore, it is worth noticing the high spread of this cloud with average values of 10µA and 1.8 µW for current and optical power, respectively.

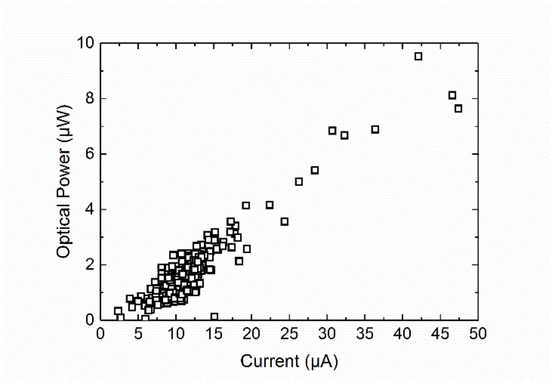

Fig. 2 Optical power versus current intensity for 300 µLEDs having 8µm diameter measured on the same display matrix.

SPICE Simulation

We have constructed an equivalent circuit model of our µLED describing its electrical and optical behaviour. This simple model consists of a SPICE LEVEL 1 ideal diode, a series resistor (RS) related to electric contacts, and a parallel resistor accounting for reverse leakage. Taking into account the external quantum efficiency (EQE) of our µLEDs we have emulated its optical output by a current-controlled voltage source (H). The output of this latter source gives the optical power (P_{opt}), but expressed in volts:

$$P_{opt} = \frac{I_D}{q} \times EQE \times \frac{hc}{\lambda} \quad (1)$$

where I_D is the µLED current, h, c and λ are Planck's constant, light vacuum celerity and the emission wavelength of our µLED, respectively.
In order to understand above experimental results we have introduced a Gaussian distribution with a variation of 10% at 3σ on the value of RS which allowed us running Monte Carlo simulations with our model. A uniform probability distribution between values of 5% and 7% has also been used for EQE corresponding to previously reported measurements on our µLEDs [6].

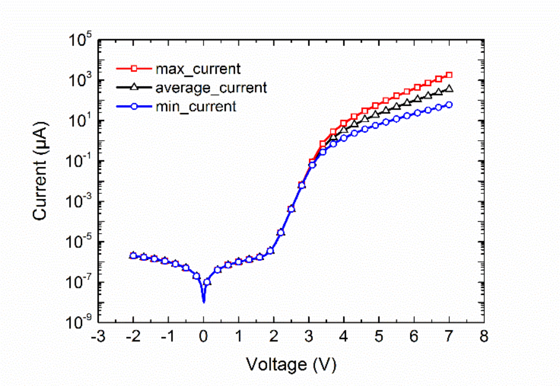

Fig. 3 Simulated current-voltage characteristics of 8µm diameter µLEDs. Maximum and minimum curves correspond to 3σ spread current output.

We show on figure 3 the simulated current-voltage characteristics of our 8µm sized µLED after 10,000 Monte Carlo runs, where the average, maximum and minimum output current limits are represented. It is obvious that RS plays an important role on the current level beyond the threshold voltage of the µLED. This has as consequence an immediate effect on the light power emitted by the µLED. Indeed, we have represented on figure 4 the output distribution of emitted light power taken at a bias of 4.5V as a matter of comparison with experimental results.

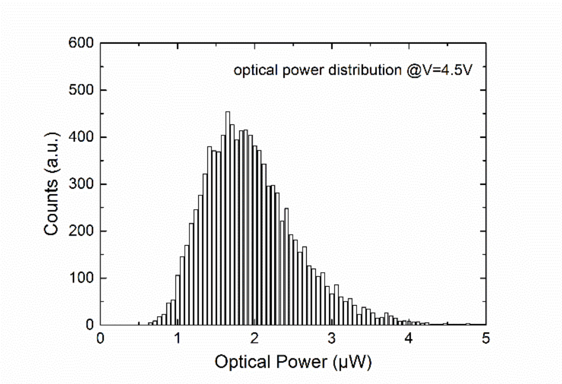

Fig. 4 Simulated optical power distribution at a bias of 4.5V for an 8µm diameter µLED after 10000 Monte Carlo runs.

This distribution show a mean value corresponding the average optical power value represented on figure 2. Moreover, we also observe that this spread shows a Gaussian like allure with a tail towards high values of optical power. Again, this is in good agreement with the results shown on figure 2.
By consequence our simple SPICE model describes well the electro-optical behaviour of the µLED and endorses the hypothesis that contact resistances plays an important on carrier's electric injection in the µLED. Therefore the optical power spreading observed on our microdisplay, and shown in figure 1, is at first order related to a discrepancy in carriers injection limited by µLEDs contacts.

3. Conclusions

We have shown that electroluminescence dispersion in our microdisplay is primarily due to a variation of carriers injection caused by a non-uniform contact resistance. Improvement of this parameter is therefore very important to achieve high performance, homogeneous LED microdisplays.

Acknowledgements

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