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Impact of GaN µLEDs aspect ratio on bandwidth and efficiency

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Abstract: Gallium Nitride (GaN) microLEDs have received a lot of attention in the field of microdisplays due to their interesting properties, such as high luminosity and robustness, and they are also gaining interest in the field of Visible Light Communication (VLC). With this increasing interest, studying carrier dynamics in these devices is crucial to understand how the recombination mechanisms affect their performance. In this paper, we quantify the effect of perimeter over surface ratio on the performance of Multiple-Quantum-Wells InGaN/GaN µLEDs.

GaN µLEDs emerged as an attractive solution for VLC applications, including chip-to-chip optical communication[1], aiming for communication at low current density J for low power consumption. Carrier recombinations in µLEDs occur in 3 main mechanisms: Shockley-Read-Hall (SRH) non-radiative recombination, radiative recombination and Auger non-radiative recombination[2], each having a different lifetime. We can estimate the effect of each process on the differential carrier lifetime τ by using the ABC model, which assigns parameters A, B and C to represent each recombination process respectively, as [2]:

$$\tau^{-1} = A + 2BN + 3CN^2 \quad (1)$$

As it can be seen from equation (1), at low J (i.e. low N), the dominant process is the SRH recombination, which happens in defect sites and surface states due to dangling bonds, lattice defects and impurities present at the side walls of the µLED [3]. These states decrease the efficiency of the µLED, so passivation processes are applied on the µLED's sidewalls to mitigate their effect. To investigate the influence of surface states on µLEDs' performance in terms of efficiency and bandwidth in this regime and the effectiveness of our passivation technique, we characterized c-plane GaN µLEDs consisting of 5 Quantum wells and emitting in the blue wavelength range (~ 450 nm) grown on 200 mm Si substrate, passivated by depositing a thin Al_2O_3 layer on the µLED's edge. At high J (7 kA/cm²), devices on this wafer can reach a high bandwidth of 600 MHz for devices at a size of 324 µm². The µLEDs under investigation are rectangular µLEDs that have constant area (256 µm²) but different aspect ratios, leading to a varying perimeter over area ratio.

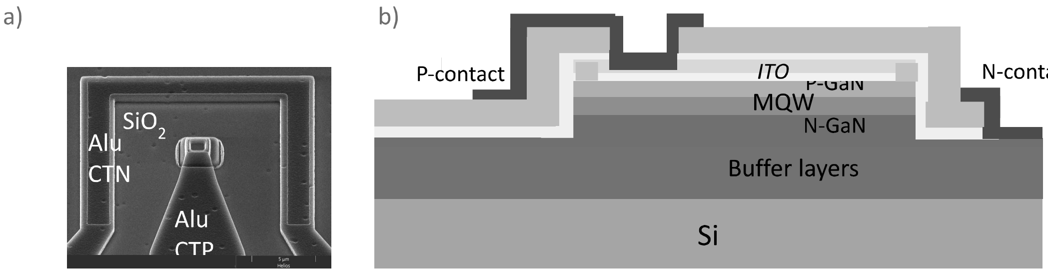

Figure 1: a) MEB image of a device on our wafer and b) Cross view of our µLEDs.

Increasing the perimeter to area ratio of a µLED at constant area will lead to an increase in the portion of non-radiative recombination (larger A parameter) [2], which decreases efficiency. Since, at low J, carrier lifetime is dominated by the A parameter, increasing this parameter will also lead to a decrease (increase) in lifetime (bandwidth). To verify this, both direct current (DC) and small-signal scattering-parameters (S-parameters) characterizations were carried out on these µLEDs. Note that we have devices with the same aspect ratios but different orientations, to compare if having one plane (width W or Length L) longer than the other affects the µLED's performance. The range of J was between 240 and 360 A/cm², where at the same applied voltage and µLED area, J increases with increasing number of surface states (perimeter) due to the increase of current leakage through the surface states.

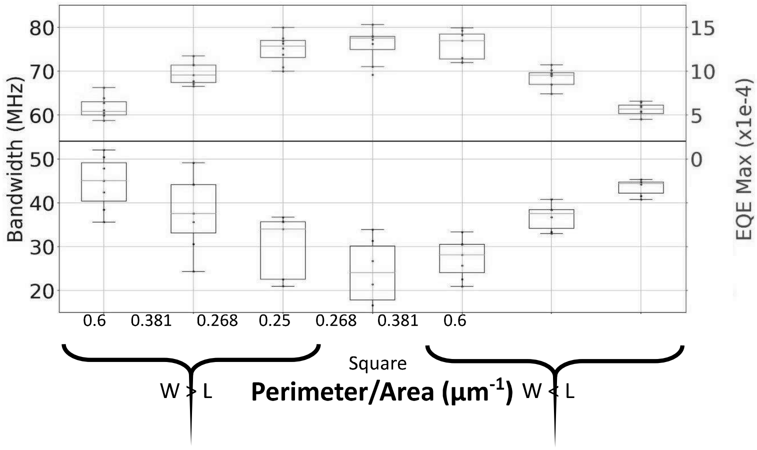

Figure 2: Bandwidth and External Quantum Efficiency (EQE) results from the measured devices at constant voltage (8V).

As shown in Figure 2, our results are in agreement with the theoretical assumption: as perimeter over surface ratio increases, efficiency decreases but the bandwidth increases, indicating an increase in SRH recombinations. In addition, these results show that even though a passivation process was performed on the devices, surface states still have a considerable effect on carrier dynamics, meaning that the passivation process was not sufficiently effective. Having one plane longer than the other does not seem to affect the µLED's performance.

This characterization technique can provide a way to measure the effectiveness of different passivation processes. Moreover, by estimating the effect of changing the aspect ratio of a µLED on both optical power and bandwidth, we may find a compromise between sacrificing some efficiency to increase bandwidth, which could be beneficial for the overall device performance in data communication applications.

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