Modeling the electrical characteristic and degradation mechanisms of UV-C LEDs

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I. INTRODUCTION

In this paper, we investigated the degradation mechanisms that negatively affect the reliability of UV-C LEDs. In particular, we modeled the process that involves trap generation identified through experimental electrical characteristics and contact degradation by means of numerical TCAD simulations.

In this study, we investigated a single QW UV-C LED with emission wavelength of 265 nm, and an area of $10^{-3} cm^{-2}$. The sample has been tested with a constant current stress at 100 A/cm^2 (100 mA) for more than 300 h (19000 min). Figure 1 reports the electrical characteristics before and after stress. We subdivided the electrical characteristic into two regions: region (a) above the turn-on voltage, where the effects of the equivalent series resistance prevails; we could observe a shift of the turn-on voltage toward higher voltages and an increase in the equivalent series resistance after the stress.

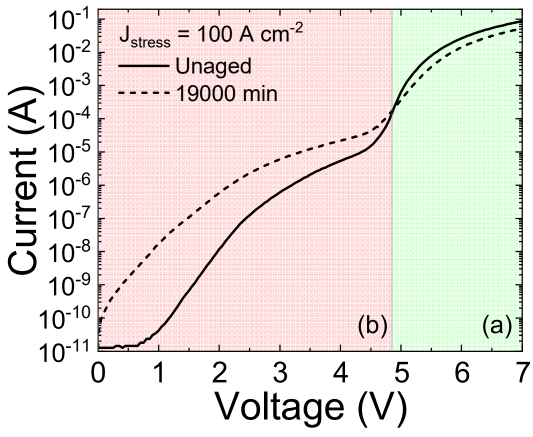

Figure 1: Electrical characteristic before and after the ageing test.

The region (b) is dominated by the forward leakage current generated by the presence of defects in the space charge region [1], that act as traps for trap-assisted tunneling processes (TAT) [2]. The increase in forward leakage current indicates a rise in the trap concentration in the depletion region during the ageing test [3]. To model these mechanisms, we created a model of the device that implements the structure through TCAD Sentaurus [4], [5], using typical parameters found in literature [6]–[11] .

II. MODELING DEGRADATION NEAR THE CONTACT

The high current region is affected by a change in the turn-on voltage and by an increase in series resistance during the ageing. These effects are due to the degradation of the contact properties and/or semiconductor [12], [13]. The largest impact on this trend is caused by the de-activation of Mg acceptors adjacent to the p-contact. In particular, during the ageing, a partial passivation of Mg doping might happen [13], [14] leading to a thicker tunneling barrier at the p-contact. Thus, hole injection is obstructed, causing a decrease in carrier injection, as illustrated in Figure 2.

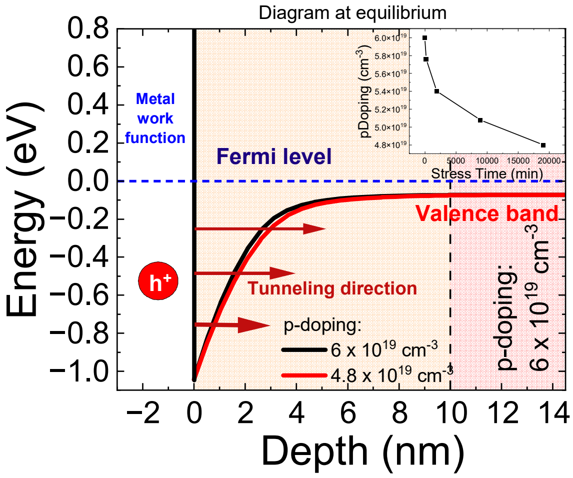

Figure 2: Model for the degradation of the p-contact. Direct tunneling is implemented in the first 10 nm adjacent to the metal. In this region, a passivation of Mg doping happens (whose simulated trend is in the insertion).

Therefore, we define the model of p-contact as a Schottky contact with a work function equal to 6.35 eV (Platinum). We considered direct tunneling as the dominant injection process from the metal contact to the first 10 nm of the p-GaN layer and, and after a first calibration of the tunneling mass for holes, we reached a good reproduction of the initial electrical characteristic at 0 min. To reproduce the aged curve, we proceeded by decreasing the p-doping concentration of the first 10 nm of p-GaN close to the contact and by slightly increasing the series resistance.

III. MODELING TAT

The forward leakage current, as demonstrated several times [2], [3], depends on the TAT. We reproduced this mechanism by means of the implementation of different nonlocal meshes to simulate different tunneling paths in the depleted region (interlayer). Here, we collocated traps at $E_C - 3.5\ eV$ as experimentally demonstrated in [15], whereas we defined a NLM for electrons from the interlayer/LB interface toward the traps and three different NLMs for holes from the EBL toward the traps in the interlayer, as illustrated in the simulated band diagram in Figure 3.

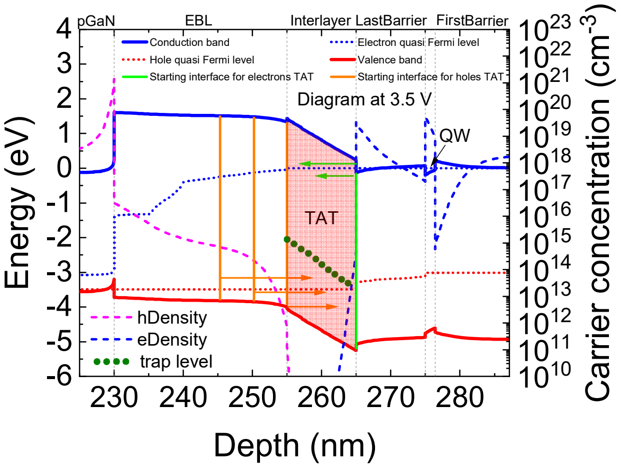

Figure 3: Simulated band diagram at 3.5 V and schematic representation of the implemented model for TAT.

In this way, when at low voltages the carriers are energetically aligned with traps, they should tunnel into the interlayer, close to the defects, where they recombine through an additional implemented SRH-like recombination process, generating the leakage current [2], [4], [16], [17]. To reproduce the curves at 0 min, we collocated a decreasing trap concentration in the interlayer (peak in EBL), and calibrated the relative tunneling masses. Subsequently, we reached a good correspondence with the aged curve simply by increasing the defect density in the interlayer and reducing the parasitic shunt resistance, as reported in Figure 4. This confirmed the hypothesis of trap generation/diffusion in the depletion region from the EBL toward the active region during the stress test.

IV. CONCLUSIONS

In conclusion, we reached a good agreement between experimental measurement and numerical simulations, both in the forward leakage current region and over the turn-on voltage. In particular, we modeled the leakage current by considering an increase in the TAT components, and the drive voltage increase with a Mg deactivation model for the p-contact. Therefore, we propose a generation/diffusion of defects from the EBL toward the active region, and a partial passivation of Mg in the region adjacent to p-contact during the stress test.

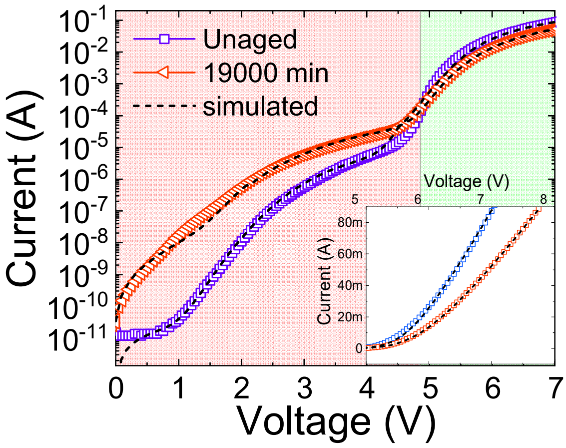

Figure 4: Comparison between the experimental I-V curves and the simulated ones before and after the ageing test. The insertion reports the same curves in linear scale.

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