

Degradation of InGaN-based optoelectronic devices under electrical and optical stress

Carlo De Santi^{*1,2}, Matteo Meneghini¹, Alessandro Caria¹, Nicola Renso¹, Ezgi Dogmus³, Malek Zegaoui³, Farid Medjdoub³, Enrico Zanoni¹, and Gaudenzio Meneghesso¹

¹Department of Information Engineering, University of Padova, Padova, 35131, Italy

²Centro Giorgio Levi Cases, University of Padova, Via Marzolo 9, 35131, Padova, Italy

³IEMN-CNRS, Avenue Poincaré CS 60069, 59652, Villeneuve d'Ascq, France

*carlo.desanti@dei.unipd.it

We provide experimental evidence for optical damage in InGaN/GaN-based optoelectronic devices, by means of stress tests on InGaN/GaN high periodicity MQW structures. Up to now, only current-driven or temperature-induced degradation processes have been investigated, and optical damage is accounted for only as COD in laser diodes.

The devices under test are 25 pairs of In_{0.15}Ga_{0.85}N/GaN multi quantum-wells, with 2.2 nm thick QW and 4.8 nm thick barrier. The p-side is Mg:GaN ($5 \times 10^{17} \text{ cm}^{-3}$) and the n-side Si:GaN ($5 \times 10^{18} \text{ cm}^{-3}$), and the device is grown on a sapphire substrate (inset of Fig. 1). The first set of stress were carried out in short-circuit condition under illumination with a 405 nm, 361 W/cm² laser diode, leading to a significant decrease in the short circuit current (see Fig. 1) confirmed by current-voltage characterization under optical excitation (Fig. 2 (a)), and to a lower maximum electrical power supplied by the cell (Fig. 2 (b)). The variation over time is shown in Fig. 3. Photocurrent spectroscopy experiments were used to collect information on the creation of deep levels. A broad photocurrent edge at 530 nm is shown to increase as a consequence of stress (Fig. 4). This spectral emission is usually ascribed to the yellow luminescence of gallium nitride and suggests the increase in gallium vacancy density [1] and/or complexes involving carbon in nitrogen substitutional position [2] or oxygen [3], that lead to the degradation of the device.

Those devices can be used for testing optically-induced degradation. Degradation is driven by energy provided to the atoms in the lattice, usually by energetic electrons (current) and phonons (temperature). Photons with energy higher than the bandgap are intrinsically present in high concentration in optoelectronic devices, therefore their possible role as degradation cause has to be investigated, especially when the photon energy is very high, as in the case of UV devices. We carried out additional stress tests in open circuit condition at 361 W/cm². The photoluminescence maps reported in Fig. 5 show a clear degradation in the region of the device illuminated by the laser beam. The different PL intensity is not caused by a variation in the device reflectivity, which remained stable (Fig. 6). We estimated a 30°C temperature for the device under stress, a value that should induce no temperature-related damage in the highly stable gallium nitride. We carried out additional stress tests on an untreated device at 100 °C, to understand the role of the temperature. Results (not shown here) are compatible with an additional degradation mode, namely the intake of elements from the air into the non-passivated device. The same degradation mechanism is present also during thermal stress of the optically-degraded device, suggesting that the degradation caused by the optical stress is not related to the effect of the temperature. As the source of the degradation, the possibility of direct lattice damage due to photon absorption is not likely, given the significantly higher bonding energy of GaN (8.9 eV [4,5]). An option is the de-hydrogenation of gallium vacancies: the process is known to affect the optical performance of a device [6] and the energy required for the de-hydrogenation process was computed to be lower than the energy gap [7].

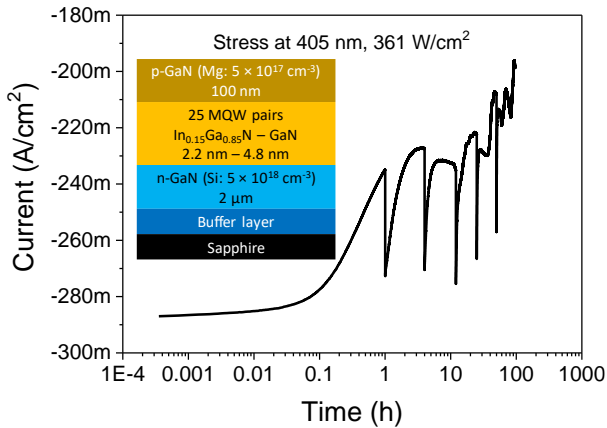


Fig. 1. Schematic cross section of the device under test and short-circuit current degradation during stress in short-circuit condition.

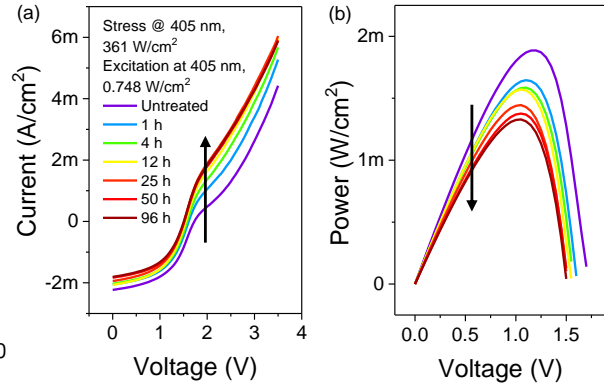


Fig. 2. (a) Illuminated I-V after every stress step in short-circuit condition and (b) corresponding electrical power supplied by the DUT.

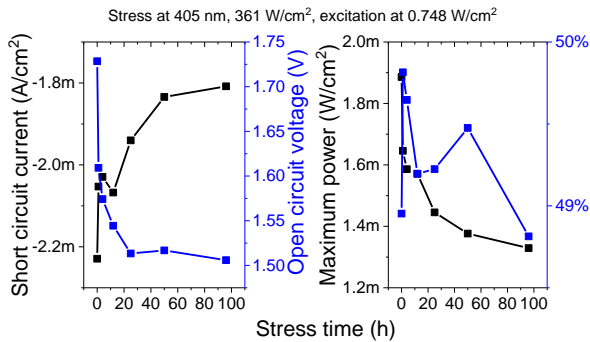


Fig. 3. Dependence on short-circuit stress time of (a) short-circuit current and open circuit voltage and (b) maximum supplied electrical power and fill factor.

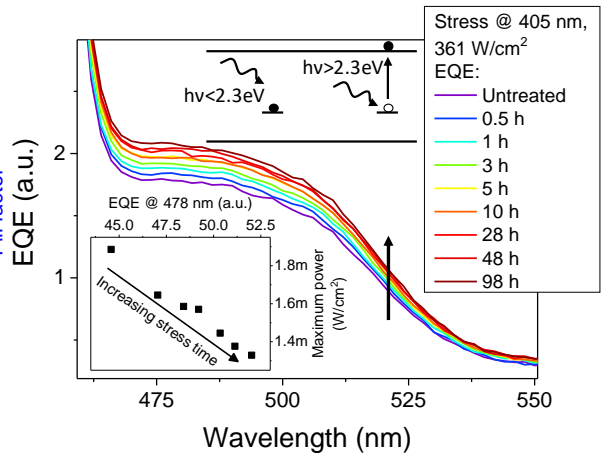


Fig. 4. Increase in photocurrent edge at 530 nm and (inset) its correlation with the reduction in the supplied electrical power during stress in short-circuit condition.

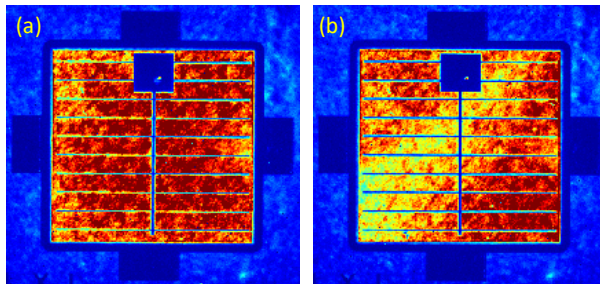


Fig. 5. Photoluminescence map of a device stressed in open circuit condition (a) before and (b) after stress

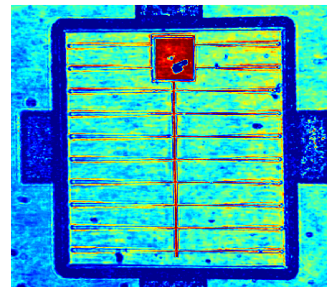


Fig. 6. Reflectivity map of the device stressed in open circuit condition showing no variation causing the difference detected in Fig. 5.

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