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Kelvin Probe Force Microscopy under variable illumination: a novel technique to unveil charge carrier dynamics in GaN

T. Frontiers of in-situ materials characterization - from new instrumentation and methods to imaging aided materials design

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Abstract

Kelvin probe force microscopy (KPFM) permits to map the contact potential difference (CPD) between a probing tip and a sample with nanometric resolution. By measuring the CPD in darkness and under illumination, we can map the surface photovoltage (SPV), which can shed light onto the different processes of charge transport, recombination and trapping in the material. Herein, we use a characterization method based on KPFM under variable illumination by showing two case studies: n.i.d. GaN-on-Si and GaN/InGaN MQW mesa structures. The KPFM protocol consists on measuring the SPV as a function of the laser power, which allows us to follow the SPV during the generation and recombination of charge carriers and relate it to the topography. These measurements were complemented by cathodoluminescence (CL), which counts with nanometric resolution too. For both studied samples, we measured a long SPV decay time after turning off the laser (around 70 s), compared to the carrier lifetimes reported in bibliography, on the order of ns or ps, suggesting that this decay does not correspond only to recombination but also to de-trapping from defect energy levels. Regarding the n.i.d. GaN on Si sample, its SPV curve showed two different components, independently of the tip position: one with positive sign, attributed to the transfer of holes to the surface due to the upwards band bending, and a negative signal, pinned on the trapping of electrons on defect levels. This evolution of the SPV curve as a function of laser power and time allowed us to propose a model for the charge trapping dynamics during and after illumination. Finally, lower SPV and higher time decay

constants were measured around dislocation pits, indicating that the charge trapping mechanisms detected by our KPFM protocol could be the origin of the lower radiative recombination rate on dislocations, measured by CL.

In the case of the GaN/InGaN MQW mesas, the SPV decay after illumination could be better described by a double exponential, indicating the presence of at least two different dynamics on the de-trapping process with same sign. Additionally, there was no SPV decrease near the border of the mesas, contrary to the light emission intensity maps obtained by CL, meaning that the border effect is not caused by the charge trapping processes detected through our KPFM protocol but by a different mechanism. Finally, we mapped the light emission efficiency of the top p-GaN layer and, unlike the MQW light emission, it did not decrease near the border of the mesas, indicating that the border effect is not originated nor influenced by this layer. This work, done at CEA's NanoCharacterization PlatForm (PFNC), was supported by the "Recherches Technologiques de Base" programme, the French Agency for National Research (ANR) via Carnot funding, as well as by PowerElec project, which has received funding from the EMPIR programme.