Characterization and Modelling of C-doped buffers in GaN HEMTs

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GaN devices whether for RF or switching applications are undoubtedly the nowadays more promising devices for improving functionality and efficiency of modern electronic systems. The most adopted structure so far is the lateral HEMT one which combines both the high electric field strength property of the GaN material with the high mobility electron channels that can be formed at the AlGaN/GaN heterostructure.

Being a lateral structure and due to the need of withstanding large operating voltages, insulating layers are needed to prevent vertical and lateral conduction during off-state device operation. Carbon doped GaN buffer layers have been proved since their first adoption to be suited for achieving the device blocking capabilities required in power applications [1]. Nevertheless, their introduction within the device epitaxial structure also led to the onset of a limiting mechanism known as dynamic on-resistance (R_{ON}) degradation. Said phenomenon typically shows up when the device is rapidly switched on after biasing it into a high voltage off-state condition, resulting in an increase of the device R_{ON} and the onset of a time dependence, i.e. dynamic R_{ON}. This mechanism is quite detrimental for device operation since larger than expected R_{ON} values are severely impacting the operation of the device but also strongly undermining the expected improvement in efficiency due to the larger conduction losses related to the increased device R_{ON}.

An in-depth comprehension of the role of Carbon dopants within the device epitaxy thus became mandatory to understand its influence on device performance. In [2] the observed current decrease in carbon-doped GaN test structure during back gating measurements has been explained simply by means of a thermally activated hole-emission process with E_A=0.9 eV, which basically corresponds to the distance of the acceptor-like hole-trap level from the GaN valence band. The proposed hole-trap model basically relies on the emission of holes from acceptor traps which becomes then negatively ionized when a large voltage is applied in off-state conditions. When the device is then turned on, the negatively ionized acceptor creates a negative charge buildup within the buffer layer partially depleting the electron channel and thus increasing the R_{ON} values.

The adoption of the hole-traps model for explaining the electrical behaviour of Carbon-doped buffer layers has also allowed to understand several other phenomena observed during device R_{ON} characterization. The often observed dynamic-R_{ON} bell-shape degradation at the increase of the device drain voltage has been for example explained in [3]. With the aid of numerical simulations, it has been shown that at the increase of the drain voltage the R_{ON} degradation would be expected to increase if no other mechanisms, beside the hole-emission from the acceptor traps, would take place. At the increasing of device voltages though, electric field driven phenomena such as example impact ionization will become more likely to happen. Simulations showed that the onset of impact ionization leads to the formation of holes within the buffer region thus leading to a compensation mechanism of the negatively ionized acceptor traps with a consequent recovery in the electron channel density, i.e. a lowering of the device R_{ON} at the increase of the applied off-state drain voltage.

In conclusion, while still several aspects related to the Carbon-doping within the insulating layers need to be investigated, several ones have been understood thus helping the development and the improvement of device performances that has been experienced in the last years.

References

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