

E_C -2.0 eV trap-related dynamic R_{ON} in GaN/Si MISHEMTs

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Abstract

Large dynamic on-resistance due to a trap at E_C -2.0 eV is observed in industry-supplied AlGaIn/GaN MISHEMTs. This trap is likely in the GaN buffer and possibly related to carbon.

AlGaIn/GaN metal-insulator-semiconductor high electron mobility transistors (MISHEMTs) for high voltage switching applications are promising due to the ability to simultaneously achieve high breakdown voltage and low on-resistance beyond the theoretical limits of Si technology [1]. However, electrically active defects in these structures can negatively impact the device operation leading to increasing static on-resistance (R_{ON}), dynamic R_{ON} , and threshold voltage instabilities [2]. In this work, we correlated degradations to a specific trap, identified its physical location and possible physical source using MISHEMT-based defect spectroscopy.

The AlGaIn/GaN MISHEMTs in this study were fabricated on a Si (111) substrate with a dielectric layer in the access regions and under the gate. Multiple field plates were optimized to achieve a breakdown voltage in excess of 600V. On the same wafer, 300 μm x 300 μm AlGaIn/GaN Schottky diodes were fabricated without the dielectric layer to investigate the location and physical source of the trap(s).

At large off-state V_{DS} , the MISHEMTs exhibited large dynamic R_{ON} with a ~ 400 s time constant determined by fitting with an exponential decay function (Fig. 1a). An onset to the dynamic R_{ON} is evident in Fig. 1b with a threshold at 200 V, and the dynamic R_{ON} reaches $\sim 15X$ higher than the static R_{ON} . If the dynamic R_{ON} recovers due to thermal emission from a defect state, the dynamic R_{ON} would exhibit strong temperature dependence, but Fig. 2 shows the dynamic R_{ON} transients are temperature independent. To further explore the trap(s) responsible for the dynamic R_{ON} , constant drain current deep level optical spectroscopy (CID-DLOS) measurements were used [3]. The sample was subjected to off-state V_{DS} biasing of 250 V then the dynamic R_{ON} transient was recorded with the sample subjected to monochromatic light. In Fig. 3 the steady-state R_{ON} is plotted after 100 s with monochromatic light shining. This time is significantly shorter than the dynamic R_{ON} time constant so if the photon energy is lower than the trap energy the trap does not emit and the R_{ON} remains high. If the trap emission is stimulated optically (i.e. $h\nu > E_C - E_T$), the dynamic R_{ON} will quickly return to the static R_{ON} . Fig. 3 shows a single onset in the dynamic R_{ON} where it recovers with optical energies above 2.0 eV indicating a single trap at E_C -2.0 eV that is also responsible for the temperature-independent recovery (~ 300 s in Fig. 2). From the recovery and using the model to estimate trap concentrations in HEMTs [4], the trap density of this level was estimated to be $9.6 \times 10^{12} \text{ cm}^{-2}$, which is very close to the 2DEG

concentration and explains the large R_{ON} change. To identify where the defect is located in the MISHEMT device and possible physical source, the Schottky diodes were used.

To determine the defect location, AlGaIn/GaN Schottky diodes were used. Fig. 4 shows the capacitance-based deep level optical spectroscopy measurements with a depletion depth of 0.7 μm , which was almost entirely in the GaN buffer layer. Figure 4 shows the same E_C -2.0 eV trap as the MISHEMT measurements. The fact that the depletion is almost entirely in the GaN buffer means the measurement is mostly sensitive to traps in the buffer, so the presence of the E_C -2.0 eV trap suggests this level is a GaN buffer trap.

To confirm the location of the E_C -2.0 eV trap, nanometer-scale deep level optical spectroscopy (nano-DLOS) was performed on the AlGaIn/GaN Schottky device. Nano-DLOS is a scanning probe microscopy technique where the surface potential is monitored at a fixed position. This allows lateral mapping of defect concentrations and the presence of the 2DEG at the AlGaIn/GaN interface acts to screen any trap response in the GaN from the nano-DLOS tip. The nano-DLOS results in Fig. 5 show little evidence of an E_C -2.0 eV level nor evidence of other typical GaN peaks such as E_C -3.28 eV. The only feature in the AlGaIn layer is the E_C -3.76 eV trap previously observed in similar AlGaIn material [5]. Additional evidence to the location and source of this level is available from previous studies of carbon incorporation in n-type GaN. It was found that carbon contributed to several deep levels in n-type GaN co-doped with Si and C, but C led to a level forming at E_C -1.94 eV, which is very similar to the E_C -2.0 eV level reported here indicating these levels may be the same trap [6]. These electron traps are negatively charged, which leads to a 2DEG reduction and increased dynamic R_{ON} .

It is demonstrated that large dynamic R_{ON} is present in these MISHEMTs due to a high concentration of E_C -2.0 eV traps likely in the GaN buffer that are possibly related to the presence of carbon. This suggests that careful buffer design and limiting carbon incorporation is necessary to reduce R_{ON} .

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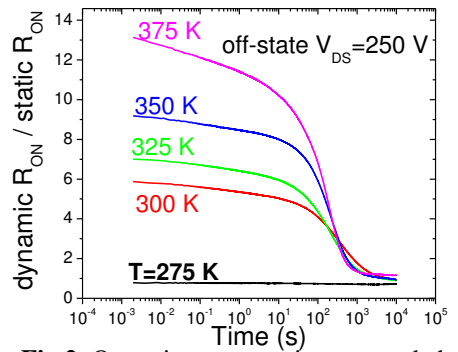
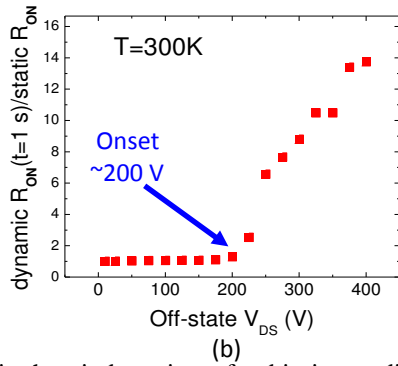
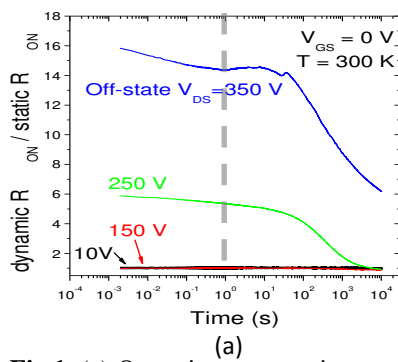


Fig.1. (a) On-resistance transients recorded in the triode regime after biasing to different off-state V_{DS} conditions plotted relative to the static R_{ON} . Up to 150 V off-state V_{DS} , no significant increase in dynamic on-resistance was observed. Because this process only happens with large V_{DS} and threshold voltage shifts are small, this indicates traps in the drain access region are responsible. (b) On-resistance sampled at 1 s after switching the MISHEMT. The sharp onset at 200 V, capacitance-voltage measurement of the MISHEMTs gate-drain terminals [7], and modeling indicate that the dynamic R_{ON} likely results when the electric field reaches a threshold at the edge of the longest field plate and that the electron trapping likely occurs in this region.

Fig.2. On-resistance transients recorded in triode conditions after biasing to off-state $V_{DS} = 250$ V for different baseplate temperatures. The time constant of the dynamic R_{ON} transient has negligible temperature dependence, which suggests a non-thermally activated trap.

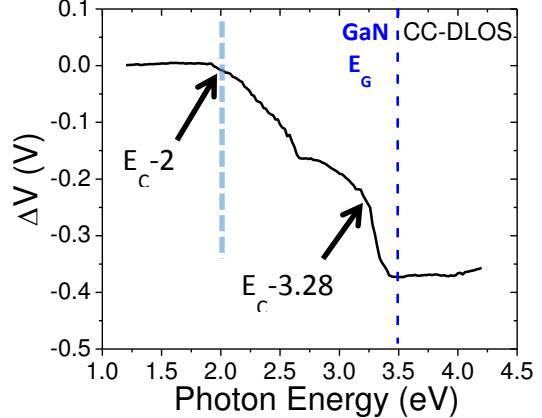
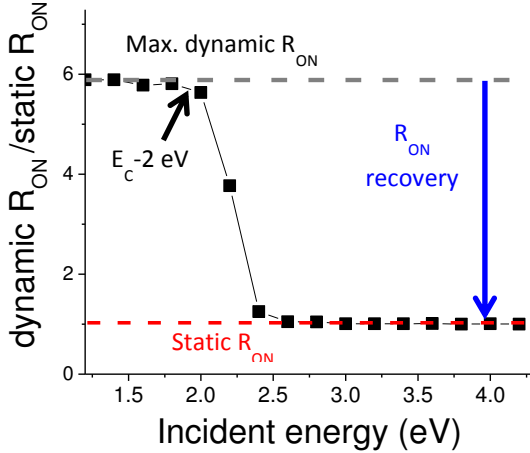


Fig.3. Constant drain current DLOS results from the MISHEMT. In the dark and at incident photon energies < 2.0 eV, R_{ON} remained approx. constant at the peak dynamic R_{ON} (~6X higher than the static R_{ON}) for $>> 100$ s after switching from off-state $V_{DS} = 250$ V. With light energies > 2.0 eV, R_{ON} recovers to the static R_{ON} in < 20 s. The sharp negative onset at 2 eV indicates an $E_C - 2.0$ eV electron trap is directly linked to the dynamic R_{ON} .

Fig.4. Constant capacitance DLOS on the AlGaIn/GaN Schottky test structure biased deep into depletion to be mostly sensitive to GaN buffer traps shows the $E_C - 2.0$ eV trap. The absence of AlGaIn traps and the common $E_C - 3.28$ GaN trap indicates the measurement is indeed mostly GaN sensitive. This result indicates the $E_C - 2.0$ eV trap is likely in the GaN buffer.

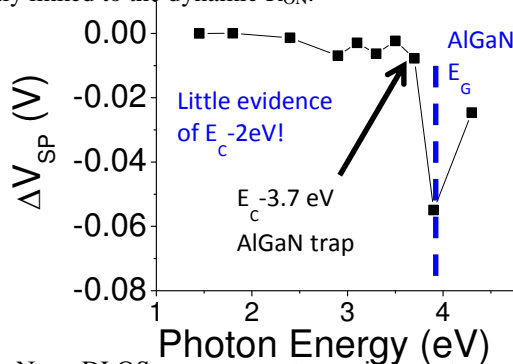


Fig.5. Nano-DLOS measurements sensitive to traps only in the AlGaIn reveal no sign of the $E_C - 2.0$ eV trap where the trap was expected to have an amplitude of ~ 0.16 V if it was present in the AlGaIn layer. This result confirms the $E_C - 2.0$ eV trap is a GaN buffer trap.

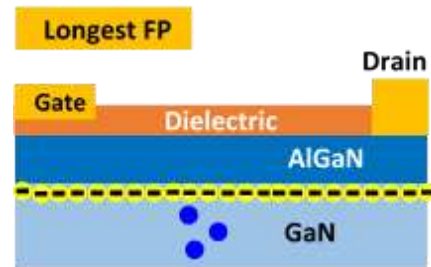


Fig.6. Schematic cross section of the GaN/Si MISHEMT shows the likely location of the $E_C - 2.0$ eV traps that are modulated with biasing above ~ 200 V (i.e. in the GaN buffer and at the edge of the last field plate where the electric fields are maximum). A level at $E_C - 1.94$ eV forms in C-doped GaN and may be the physical source of this level in the GaN buffer [4].