Trapping vs. permanent degradation in GaN high electron mobility transistors

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There is great interest in improving the electrical reliability of GaN high electron mobility transistors (HEMT). For this, the degradation mechanisms must be identified. Under high voltage stress the drain current is seen to degrade in a partially recoverable manner. This is attributed to the introduction of carrier trapping, but it also reveals the presence of additional permanent degradation [1]. Several studies have focused on the role of trapping in device degradation [2-5] but little effort has been given to identifying permanent degradation. This is particularly hard because of the relatively slow nature of trapping in electrically degraded GaN HEMTs [1]. In this work, we separate trapping-related from permanent degradation and establish how these two different degradation mechanisms contribute to the overall degradation of GaN HEMTs.

Trapping-related degradation and permanent degradation can be both seen in a typical stress-recovery test in the V_{DS}=0 state. As shown in Figure 1, after stressing the device at V_{GS}=-30 V for 30 minutes, I_{Dmax} decreases by 28%. This is beyond the critical voltage where trap formation starts [4, 6]. After stress removal, I_{Dmax} partially recovered due to detrapping over the following 30 mins [1]. After 88 days, we found that I_{Dmax} had recovered to 87% of its original value. At this point, we tried to detrap more trapped electrons, if any, by shining microscope light and UV light, or heating the device, but I_{Dmax} did not increase any further. We conclude that in this experiment, out of the 28% of I_{Dmax} drop at the end of the 30 min stress period, 13% is due to permanent degradation, while the remaining 15% is trapping-related degradation. Separately, we have found that in our devices, regardless of the amount of degradation, shining microscope light efficiently brings the device to a fully recovered point within 0.5% in 30 seconds. We have used this simple procedure to fully empty traps and in this manner separate permanent degradation from trapping effects.

In order to understand the time evolution of trapping and permanent degradation, we have performed a constant-stress experiment in the OFF state. At the beginning of the experiment and at several points during the experiment, the trapping dynamics were characterized by a drain current transient method [4]. As shown in Figure 2, as the experiment proceeds, I_{Dmax} decreases, and R_D increases while R_S remains relatively unchanged. I_{Goff} sharply increases in the first few minutes and then remains largely unchanged. In Figure 3, the time evolution of total degradation and permanent degradation are shown. These were separated by stopping the stress at periodic intervals and shining microscope light to detrap electrons. As it can be seen, permanent degradation increases throughout the experiment. Trapping-related degradation sharply increases in the early stages of the experiment and then slows down. This is clearer in detrapping transients and their time-constant spectrum (Figure 4). Short time-constant current collapse sharply increases up to around 300 min. We in fact observe an increase in a major trap level (DP1) that saturates around the same time. This level was found to be associated with detrapping from AlGaN barrier or surface [4]. Longer time constant processes continue to increase at a lower rate. This result is summarized in Figure 5. It can be seen that fast trap creation tends to saturates in 300 min while the density of very slow traps (detrapping time constant > 10 min) keeps increasing.

In conclusion, we have separated permanent from trapping-related degradation in GaN HEMTs. We have also shown that under OFF-state stress, trapping sharply increases during the early phase of the stress while permanent degradation keeps increasing throughout the stress.

References

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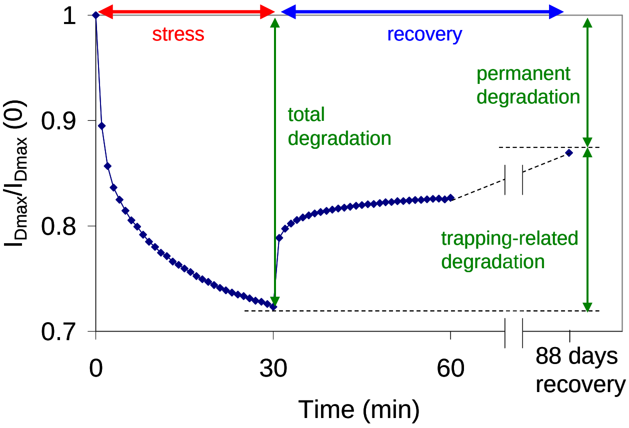

Figure 1. Change in normalized I_{Dmax} (V_{DS}=5, V_{GS}=2 V) in a V_{DS}=0 stress-recovery experiment at room temperature. The stress condition was V_{DS}=0 and V_{GS}=-30 V. After the first 30 minutes, the stress was removed while I_{Dmax} was periodically measured. The last data point was measured after 88 days of recovery.

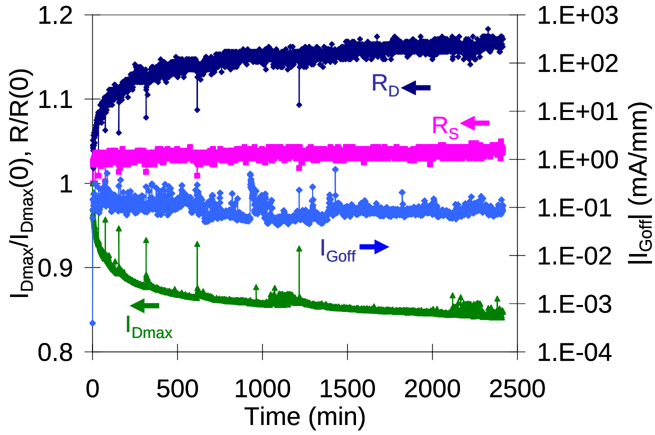

Figure 2. Change in I_{Dmax}, R_D, R_S, and I_{Goff} (I_G @ V_{DS}=0.1 V, V_{GS}=-5 V) in OFF-state stress. The stress condition was V_{GS}=-5 and V_{DS}=40 V at 100 C.

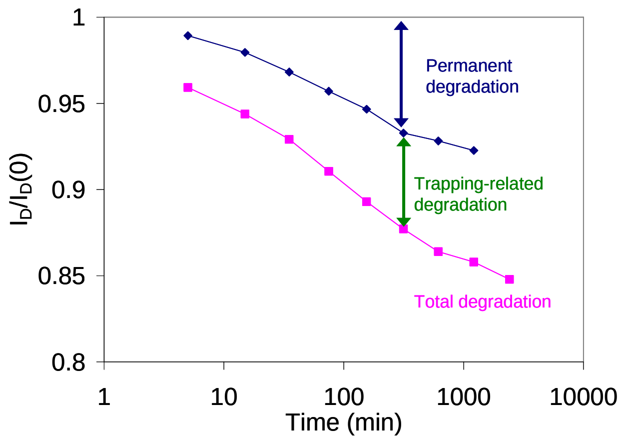

Figure 3. Total (=permanent+trapping-related) and permanent degradation in I_{Dmax} (100 C) of the experiment in Figure 2.

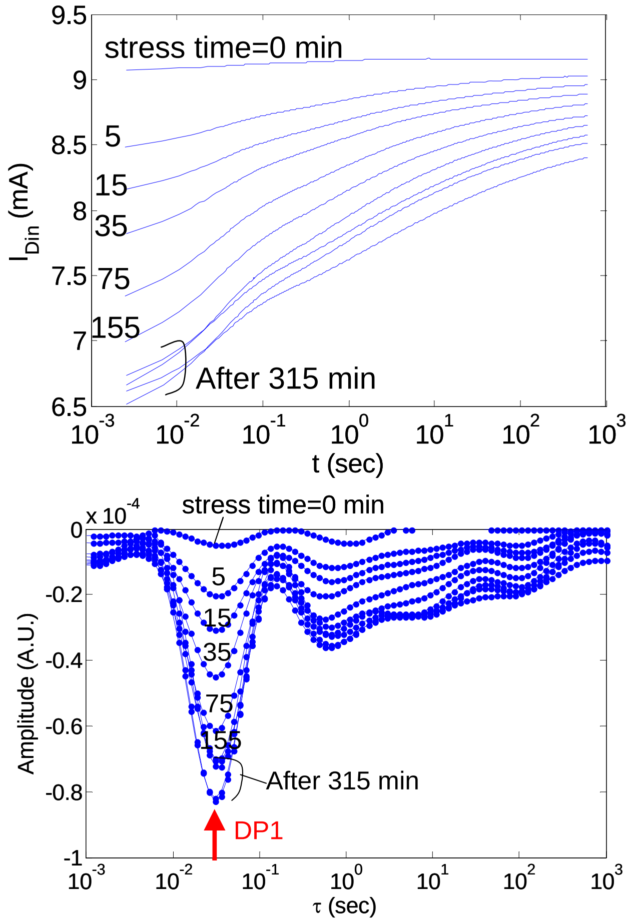

Figure 4. Detrapping transients of I_{Dlin} (upper) and corresponding time constant spectrum (lower) after applying V_{DS}=0 pulse (V_{GS}=-10 V, 1 s) for the experiment in Figure 2.

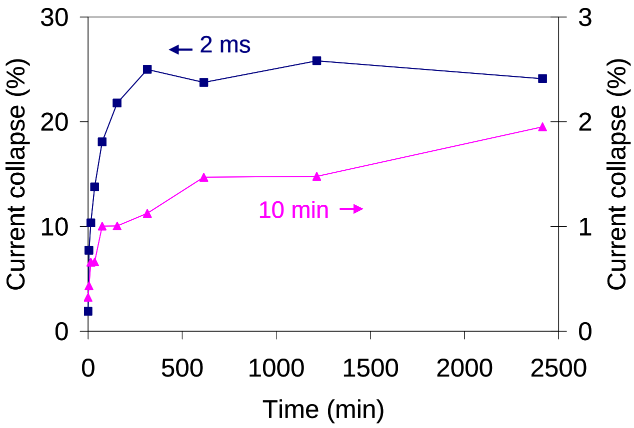

Figure 5. Change in current collapse after applying a V_{DS}=0 pulse (1 s V_{DS}=0 and V_{GS}=-10 V). The current collapse was evaluated 2 ms and 10 min after applying the pulse.

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