Suppressed Current Collapse in High Pressure Water Vapor Annealed AlGaN/GaN HEMTs

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GaN-based transistors are expected to be one of the promising devices for high power, high temperature and high frequency applications because of excellent intrinsic properties of GaN. In spite of rapid advances in AlGaN/GaN HEMT technology, however, the widespread implementation of these devices is still hampered by stability issues particularly by the well-known current collapse. There have been reports that surface treatment of O_2 plasma [1-2] immediately before insulator deposition can improve the performance of AlGaN/GaN HEMTs. Meanwhile, previous works by Yoshitsugu and co-workers [3] have demonstrated the effectiveness of High Pressure Water Vapor Annealing (HPWVA) in improving the quality of Al_2O_3 gate dielectric in n-GaN MOS capacitors. In this work, we demonstrate the effective suppression of current collapse in AlGaN/GaN HEMTs subjected to HPWVA prior to SiN passivation.

Figure 1 shows the schematic illustration of the device used in this study. The devices were fabricated using the conventional AlGaN/GaN HEMT fabrication process. As an additional surface treatment process, prior to SiN passivation, the devices were subjected to HPWVA illustrated in **Fig. 2**.

To examine the degree of current collapse in the samples, we have compared the resulting dynamic on-resistance (R_{on}) after pulsing gate signal from quiescent bias of V_{GS_off} = –5 V (off-state) to drive voltage of V_{GS_on} = +1 V (on-state) with an applied drain bias voltage of V_{DD} = 100 V through a load resistance of R_L = 10 kΩ. The gate pulse on-time (t_{on}) was varied from 1 μs to 10 s while off-time (t_{off}) was held constant at 100 ms. A detailed description of the experimental set-up is given in [2, 4]. **Figure 3** compares the resulting Normalized Dynamic R_{on} (NDR) as a function of t_{on} of the reference (w/o HPWVA) and HPWV-annealed (with HPWVA) devices under different annealing temperatures. NDR is defined as the ratio of the dynamic on-resistance to static on-resistance. All the HPWV-annealed devices exhibited relatively lower NDR which was further decreased with increasing annealing temperature, suggesting the effectiveness of HPWVA in mitigating current collapse. Following ref [5], NDR can be expressed as a sum of pure exponential terms in the form:

$$NDR = 1 + \sum_{i=1}^{n} \alpha_\mathrm{i} \exp\left(-\frac{t}{\tau_\mathrm{i}}\right) \quad , \tag{1}$$

where α_i represents the magnitude of the trapping process with time constant τ_i. By fitting the experimentally measured NDR with the above relationship, we obtained for the w/o HPWVA and with HPWVA (400 °C) devices the best fit curves (solid curves) and the corresponding exponential terms (dash curves) given in **Fig. 4** and summarized in **Table I**. The ($E_C – E_t$) energy values in the third column of the **Table I** were obtained using Shockley-Read-Hall (SRH) statistics. From the device w/o HPWVA, six trap levels were obtained. However, after HPWVA at 400 °C, only two shallow traps were detected at ($E_C – E_t$) of 0.28 and 0.37 eV. Moreover, the corresponding α_i of these traps are orders of magnitude lower than those of the reference device. These results indicate the disappearance or weakening of all the other deeper traps after the HPWVA process. As these traps are likely to be connected to current collapse, the obtained data can explain the effective suppression of current collapse in HPWV-annealed devices. **Figure 5** shows the ($E_C – E_t$) plot as a function of α_i of the devices with and w/o HPWVA. With increasing annealing temperature, it is evident that both the ($E_C – E_t$) energy level and magnitude of the trapping process α_i were decreased.

In conclusion, we have demonstrated suppression of current collapse in HPWV-annealed devices. The disappearance of deeper traps and the effective suppression of current collapse for devices with HPWVA were proposed to be due to the filling up of nitrogen vacancies (V_N) by active oxygen (or hydrogen) species generated from the high pressure water vapor on the AlGaN surface. The incorporation of oxygen was found to deactivate the deep traps [6] at around ($E_C – E_t$) = 0.6 eV, which were reported to be related to nitrogen vacancy [7].

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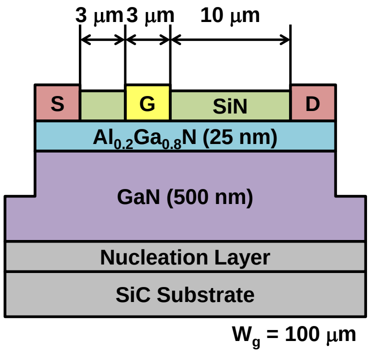

Fig.1. Schematic cross-sectional illustration of AlGaN/GaN HEMT used in this study.

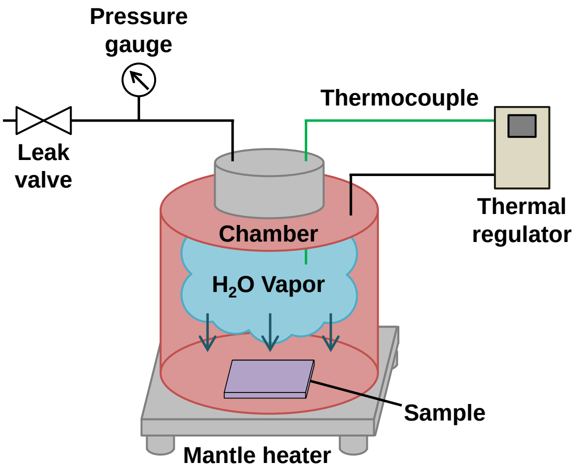

Fig.2. Schematic illustration of High Pressure Water Vapor Annealing (HPWVA) experimental set-up.

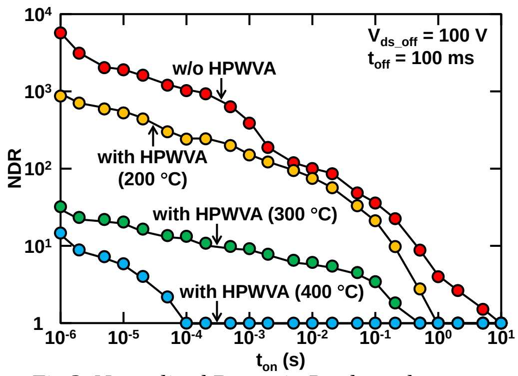

Fig.3. Normalized Dynamic R_{on} dependence on on-time t_{on} of devices w/o HPWVA and with HPWVA.

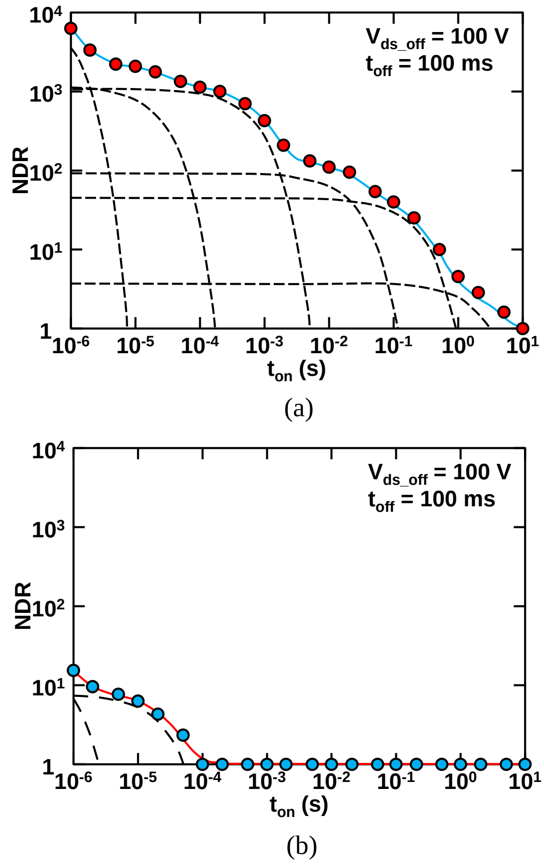

Fig.4. Measured (solid data points) and calculated (solid curves) normalized dynamic R_{on} (NDR) dependence on t_{on} of devices (a) w/o HPWVA and (b) with HPWVA at 400 °C. Dashed curves represent extracted exponential terms by curve-fitting.

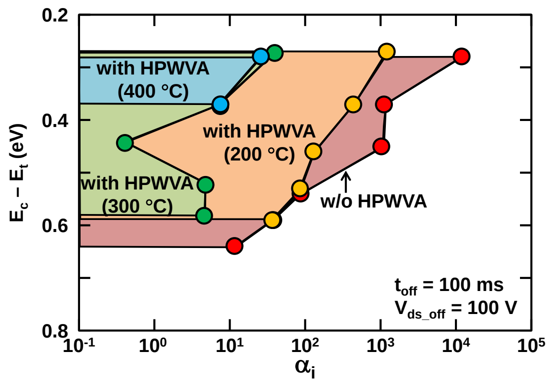

Fig.5. Trap energy level ($E_C - E_t$) as a function of the magnitude of trapping process α_i.

Table I. Summary of extracted trap energy levels ($E_C - E_t$) for devices w/o HPWVA and with HPWVA at 400 °C.

	τ_i (s)	α_i	$E_c - E_t$ (eV)
w/o HPWVA	8.0×10^{-7}	12097	0.28
	2.4×10^{-5}	1118	0.37
	7.1×10^{-4}	1042	0.45
	2.5×10^{-2}	88	0.54
	1.8×10^{-1}	38	0.59
	9.0×10^{-1}	12	0.64
with HPWVA (400 °C)	7.4×10^{-7}	25.9	0.28
	2.5×10^{-5}	7.5	0.37