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Reduction of current collapse in AlGaN/GaN HEMTs using thick GaN cap layer

Hiroshi Chonan[1], Yuichi Sakamura[2], Guanxi Piao[2], Toshihide Ide[2],
Mitsuaki Shimizu[2], Yoshiki Yano[3], Hisayuki Nakanishi[1]

[1] Department of Electrical Engineering, Faculty of Science and Technology, Tokyo University of Science.
2641 Yamazaki, Noda-shi, Chiba 278-8510, Japan
[2]Advanced Power Electronics Center, AIST, Central 2, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8568, Japan
+Phone +81-29-861-5647 E-mail: mitsu.shimizu@asit.go.jp
[3]Leading Edge Technology Development Department, Taiyo Nippon Sanso Corporation,
10 Okubo, Tsukuba, Ibaraki 300-2611, Japan

1. Introduction

GaN-based high electron mobility transistors (HEMTs) have attracted much attention as high-speed and low-loss switching device that has superior characteristics to Si power devices. But one of the problems preventing the system applications of the HEMTs is current collapse. The maximum drain current is suppressed by trapped charge in AlGaN surface, and the drain-source resistance of the HEMT becomes large. So reduction of trapped charge density is important to improve device characteristics.

One of the methods to reduce the density of electron traps in AlGaN surface is the employment of surface passivation by Si_3N_4. The Si_3N_4 films are usually formed by LPCVD or PECVD. The effect of the Si_3N_4 passivation films, however, does not prevent the current collapse effect completely, and depend on the deposition condition.

Therefore, in this study, we employed thick GaN cap layer on AlGaN barrier layer and investigated its effect by numerical simulation.

We also fabricated the HEMTs with and without GaN cap layer, and compared the drain current change in I_D-V_{DS} measurement of those HEMTs after Off-state stress bias condition.

2. Conditions of device simulation

Device simulations were performed for the HEMTs using the *synopsys-DESSIS*. Current flow in the HEMTs was calculated from hydrodynamic equations [1] with fixed lattice temperature of 300K. A schematic illustration of the simulated HEMT is shown in Fig. 1. The layer structure consists of a 1 μm bulk GaN layer, 30 nm thick AlGaN layer, and 0 ~ 300 nm thick GaN cap layer. And the material composition of aluminum in AlGaN layer is set to 20 %.

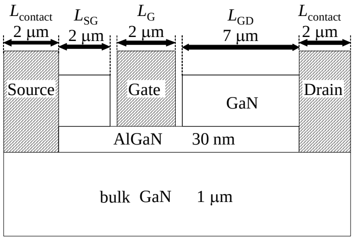

Fig. 1 A schematic illustration of the simulated HEMT

Both source and drain electrodes are put on the surface of bulk GaN layer. And gate electrode is put on AlGaN surface, and 40nm width void is allocated to the both side of gate electrode.

Fixed sheet charges at surface side and back side of interface in AlGaN layer are assumed for piezoelectric polarization sheet charges. Those sheet charges densities are -1.0×10^{13} cm^{-2} at upper side, and 1.0×10^{13} cm^{-2} at lower side [2].

Acceptor like traps and donor like traps are assumed as surface states at the surface of GaN cap layer. Density distribution of those surface states are given by eq. (1) from the DIGS model [3].

$$N_{SS}(E) = N_{SS0} \exp\left[\left(\frac{|E - E_{HO}|}{E_{0A,D}}\right)^{n_{A,D}}\right] \quad (1)$$

where N_{SS0} is the minimum surface state density, E_{HO} is the energy position of the charge neutrality level, $E_{0D,A}$ and $n_{D,A}$ are the parameters responsible for the curvature of $N_{SS}(E)$ function for donor-like states (subscript D) and acceptor-like ones (subscript A), respectively.

The values of each variables in eq. (1) are obtained by fitting the $N_{SS}(E)$ distribution curve measured at the surface of MOVPE grown GaN template [3].

The electron mobility at channel region is 1500 cm^2Vs^{-1} because the measured electron hall mobility of a wafer which is used for experiment in this study was about 1500 cm^2Vs^{-1}.

The other parameters which are used in the simulation are listed in Table 1.

To calculate the distribution of trapped electron at surface of GaN cap layer in Off-state stress, gate to source voltage (V_{GS}) and drain to source voltage (V_{DS}) were set to -6 ~ -9 V and 50 ~ 100 V, respectively.

3. Results in device simulation

Fig. 3 shows the calculated distribution of trapped electrons at surface of GaN cap layer under the condition of Off-state (V_{GS} = -9 V, V_{DS} = 60 V).

Results of reference [6] showed that current collapse phenomena become significant when the density of trapped electrons at the AlGaN surface is increased more than 10^{12} cm^{-2}.

But in Fig. 3, the calculated density of trapped electron is in the order of 10^{+5} cm^2 in maximum. So in calculation, the AlGaN/GaN HEMT structure with 100 nm GaN cap layer has possibility to prevent the collapse of drain current caused by trapping of electrons at the surface of the device.

Table 1 Parameters used in the simulation

	Unit	Value
Surface State Parameters [a]		
N_{SSO}	$cm^{-2}eV^{-1}$	2.0×10^{12}
E_{HO}	eV	1.08
E_{OD}, E_{OA}	eV	0.41, 0.81
n_D, n_A	(none)	2, 2
carrier mobility μ_e , μ_h	$cm^2V^{-1}s^{-1}$	
in GaN cap		(300 , 10)
in AlGaN		(5 , 1)
in Channel		(1500 , 10)
in bulk GaN		(300 , 10)
Band Gap [b] $E_g(x)$	eV	$6.13x+3.42\times(1-x)-x(1-x)$
Band offset [b] $\Delta E_C(x)$	eV	$0.7\times[E_g(x)-E_g(0)]$
Dielectric constant $\varepsilon_r(x)$	ε_0	$9.5-0.5x$
Gate Schottkey barrier height [c] Ni - $e\Phi_b(x)$	eV	$(1.3x+0.84)$

[a] Reference [3]
[b] Reference [4]
[c] Reference [5]

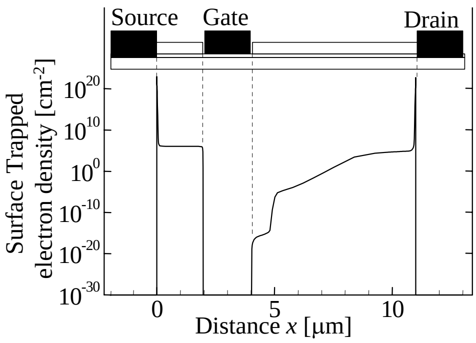

Fig .3 Trapped electron density at cap GaN surface

4. Results in fabricated device and discussion

In order to compare the difference of collapse effect in fabricated device with and without GaN cap layer, I_D-V_{DS} characteristics before (solid) and after (dashed) Off-state stress are shown in Fig. 4 (no GaN cap layer) and Fig.5 (100 nm GaN cap layer). Off-state stress bias was applied for 40 minute, and the bias voltages of V_{GS} and V_{DS} are also described in Fig. 4, 5.

The amount of decreased drain current in Fig. 4 is smaller than that of in Fig. 5. This result shows that current collapse effect was reduced in the fabricated HEMT with 100 nm GaN cap layer.

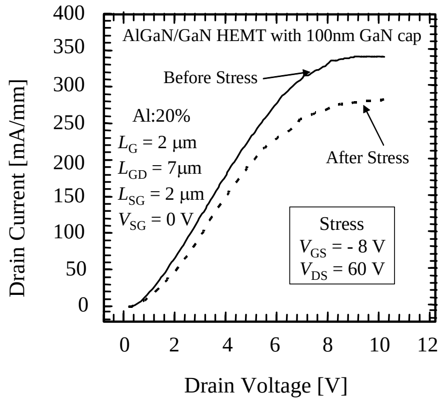

Fig. 4 I_D-V_{DS} characteristics measured before and after Off-state stress in AlGaN GaN HEMT with 100nm GaN cap layer

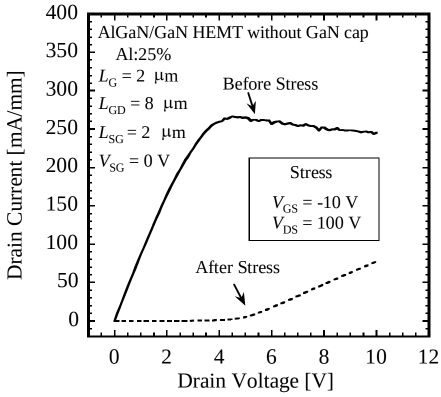

Fig. 5 I_D-V_{DS} characteristics measured before and after Off-state stress in AlGaN GaN HEMT without GaN cap layer

5. Conclusions

In order to suppress current collapse effect in Al-GaN/GaN HEMT, we employed thick GaN cap layer, and performed numerical simulation and DC characteristic measurement in the fabricated devices. The simulation results show that electron trapping at the device surface under the Off-state stress bias condition can be suppressed.

In order to investigate effect of the GaN cap layer experimentally, I_D-V_{DS} characteristics before and after Off-state stress was measured in fabricated devices with and without 100 nm GaN cap layer. The measurement results shows that current collapse was reduced in the AlGaN/GaN HEMT with 100 nm GaN cap layer.

References

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