A Highly Uniform and Reliable AlGaN/GaN HEMT

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Abstract

We describe a highly uniform and reliable AlGaN/GaN-based high electron mobility transistor (HEMT) with the surface-charge-controlled structure on a SiC substrate for microwave applications. To obtain a highly uniform device, we adopted the n-GaN-cap structure, and optimized the stress and thickness of the SiN on the n-GaN-surface. The averaged threshold voltage (Vth) of -1.69 V and the associated standard deviation of 21 mV were obtained. Preliminary reliability was characterized using a RF power stress test. A CW P_3dB RF-power measurement at Vds of 60 V exhibited good reliability over 1000 h.

INTRODUCTION

AlGaN/GaN-based HEMTs have received much attention for microwave power applications, including wireless base stations. There are many reports related to high output power characteristics [1-2]. However, a few papers exhibited high efficiency characteristics using a large gate-periphery device operated at over 50 V drain bias voltage due to instability related to current collapse. The key issue for the actual manufacturing is to suppress instability related to large-signal current collapse and transconductance (gm) dispersion. And high uniformity and high reliability are strongly required in microwave power applications for mass-production. In this paper, we demonstrate the AlGaN/GaN HEMTs with the surface-charge-controlled structure on a SiC substrate. To obtain a highly uniform and highly reliable AlGaN/GaN HEMT, we have to suppress frequency dependent instabilities, such as large gm dispersion, gate-lag and current collapse. Therefore we controlled the polarization-induced surface charge by the n-type doping in a thin GaN cap on AlGaN and stabilized n-GaN-surface between gate and ohmic electrodes using SiN passivation [3].

In addition, reliability has become another important issue to be discussed for manufacturing of AlGaN/GaN-HEMTs. For microwave high power applications, higher current density in ohmic electrodes is required. We conducted high temperature operation test for ohmic electrodes at 250 deg-C in nitrogen ambient. And we also performed the RF-stress test to investigate stability performance of AlGaN/GaN HEMTs with surface-charge-controlled structure under continuous power operation. The RF-stress test was performed under P_3dB conditions at Vds of 60 V. Pout was constant during and after a 1000-hour RF-stress test.

DEVICE TECHNOLOGY

To suppress instabilities related to frequency dispersion, such as large-signal current collapse and gm dispersion, we introduced an n-type doped GaN cap layer into the AlGaN/GaN HEMTs structure to control the polarization-induced surface charges [3]. Figure 1 shows the device structure on SiC substrate. Detail of the fabrication method has been reported in the previous papers [3-6].

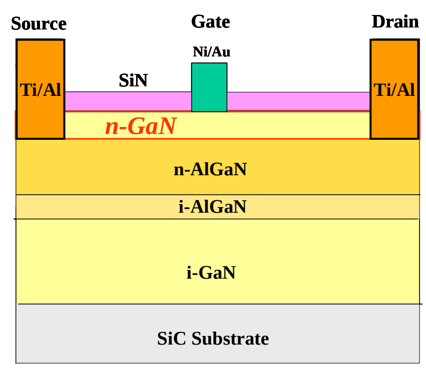

Fig. 1 Schematic drawing of the surface-charge-controlled n-GaN-cap structures. Thin n-type GaN cap layer was grown on AlGaN/GaN structure. SiN passivation was formed on GaN cap layer between electrodes.

The epitaxial layers of AlGaN/GaN HEMT in our study were grown by MOCVD on 3-inch semi-insulating SiC substrate. For the isolation, Ar ion implant technology was used. We formed both source/drain and gate electrodes by using stepper lithography. The recessed ohmic technology was introduced to obtain lower ohmic contact resistance with evaporated Ti/Al ohmic electrodes [7]. Only n-type doped GaN cap layer was removed. The gate electrode consisting of Ni/Au was evaporated onto the GaN cap layer. After forming the gate electrode SiN was deposited on the n-GaN cap layer using plasma CVD. The uniformity of this structure is determined by controlled Piezo induced charges. Thus, we adopted the surface-charge-controlled n-GaN-cap structure, and optimized the stress and thickness of the SiN.

The current-collapse-free AlGaN/GaN HEMT die was mounted on a conventional metal/ceramic package. The gate periphery is 41.28 mm with a unit gate width of 430 µm, as shown in Fig. 2. A single-chip amplifier was designed for W–CDMA base station applications with a frequency of 2.14 GHz. Quiescent drain current (Idsq) is 1.4 % Ifmax near class B, which is mainly used in base station system [6]. We measured all performance using a packaged chip on a test-fixture, which was tuned at 50 V drain bias voltage.

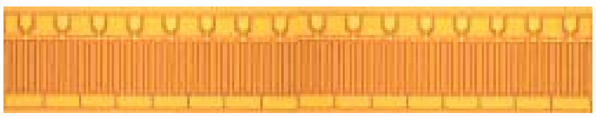

Fig. 2.Photograph of AlGaN/GaN HEMT chip.
The total gate width is 41.28 mm with a unit gate width of 430 µm.

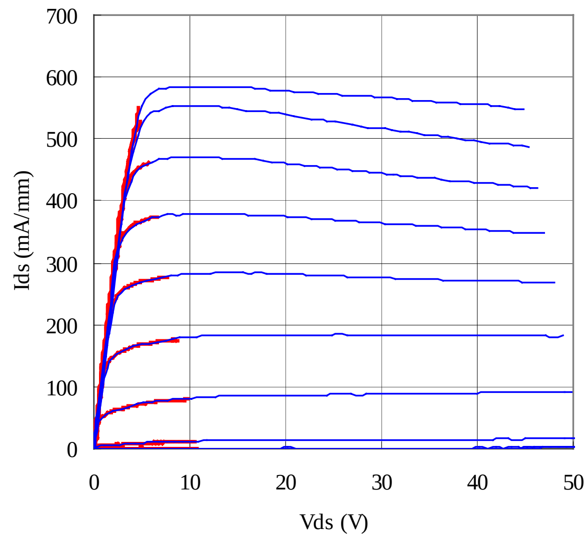

Fig. 3 Comparison of I-V characteristics at 10 V and 50 V operations using a 100-Hz curve tracer. The gate width was 40 µm. The gate voltage was swept from +2 V to –2.5 V with 0.5 V step.

RESULTS AND DISCUSSION

1) DC Characteristics

Figure 3 shows the comparison of I-V characteristics at 10 V and 50 V operations using a 100-Hz curve tracer. Compared with 10 V operations (Fig. 3 red lines), the on-resistance (Ron) of 50 V operations (Fig. 3 blue lines) did not increase. It shows the current collapse did not occur in the AlGaN/GaN HEMTs with the surface-charge-controlled structure.

Figure 4 shows I-V characteristics using a semiconductor parameter analyzer. Good pinched-off characteristics were obtained. On-state and off-state breakdown voltages were over 100 V and 200 V, respectively. The Vth is -1.70 V and the gm is 200 mS/mm.

2) Power Performance

Figure 5 shows the power performance measured at Vds equal to 50 V and frequency of 2.14 GHz under pulsed CW conditions [5 µsec (on)/45 µsec (off)]. The saturated power (Psat) measured in this configuration is 100 W. This value indicates that this device has enough power to be used at an averaged output power, 20W, required for the W-CDMA base stations.

Figure 6 shows the single-tone W-CDMA RF performance measured at 2.14 GHz. The measurement was performed at drain bias voltage of 50 V and quiescent bias current (Idsq) of 500 mA. As shown in figure drain efficiency of 34 % and power gain of 16.5 dB was achieved at average output power of 42 dBm. This result shows the device has the highest drain efficiency for base station applications in the industry.

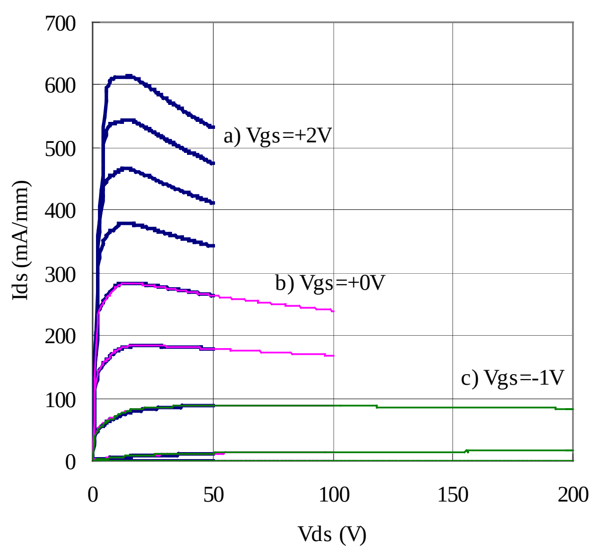

Fig. 4 I-V characteristics of 40-µm gate periphery using a semiconductor parameter analyzer. The gate voltage was swept a) from +2 V to –3 V with 0.5 V step up to Vds of 50 V, b) from +0 V to –3 V with 0.5 V step up to Vds of 100 V, c) from –1 V to –3 V with 0.5 V step up to Vds of 200 V.

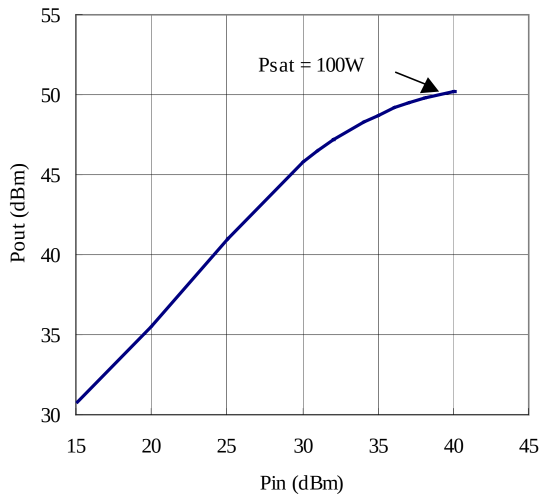

Fig. 5 Pulsed CW power measurement results of single-chip AlGaN/GaN HEMT amplifier at 2.14 GHz. Quiescent drain current is 500 mA at Vds = 50 V.

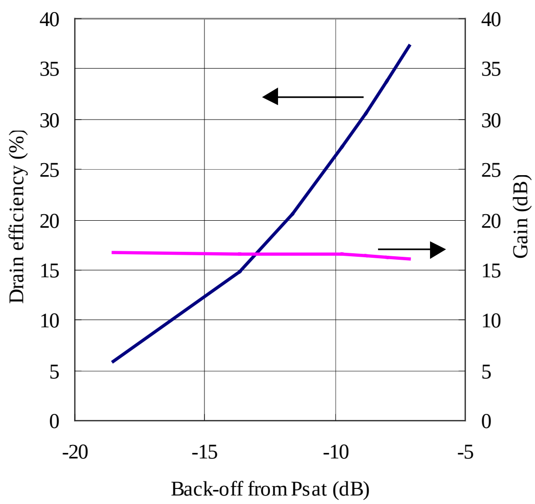

Fig.6 Single-tone W-CDMA RF performance of AlGaN/GaN HEMT measured at 2.14 GHz. Bias condition is Vds = 50 V, Idsq = 500 mA.

3) Uniformity

Full wafer DC characterization was performed on process control monitor (PCM) pattern with the gate length of 0.8 µm. 50 points were measured on a wafer.

The histogram of figure 7 shows the Vth of Vds = 10 V for AlGaN/GaN HEMTs fabricated on a 3-inch wafer. And figure 8 shows the distribution of Vth across the entire 3-inch wafer. The average Vth value of –1.69 V and the associated standard deviation of 21 mV were obtained. These results indicated that the AlGaN/GaN HEMTs were fabricated with excellent uniformity.

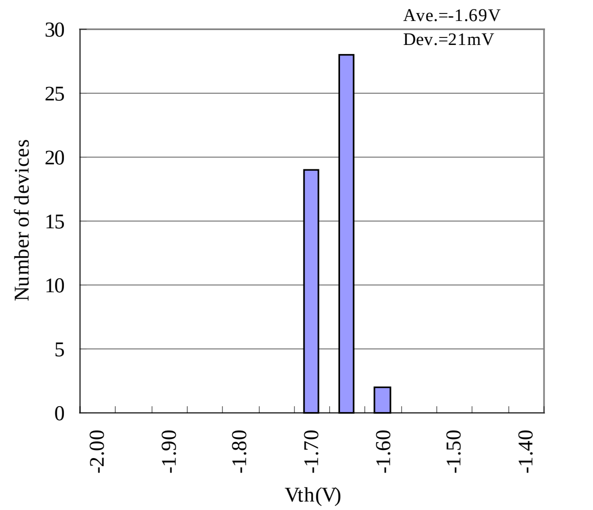

Fig.7 Histogram of threshold voltage for fabricated AlGaN/GaN HEMT

		-1.63	-1.64	-1.66	-1.66	-1.65		
	-1.66	-1.67	-1.68	-1.68	-1.69	-1.69	-1.69	
-1.69	-1.67	-1.70	-1.72	-1.71	-1.70	-1.71	-1.71	
-1.69	-1.68	-1.71	-1.73	-1.71	-1.71	-1.72	-1.71	-1.72
-1.68	-1.70	-1.70	-1.71	-1.70	-1.70	-1.70	-1.71	
	-1.70	-1.70	-1.69	-1.69	-1.70	-1.70	-1.70	
		-1.67	-1.68	-1.69	-1.67	-1.67		

Fig.8 Distribution of threshold voltage across the entire 3-inch wafer.

4) Reliability

We investigated reliability performance, a very important issue at high drain bias operation. The high temperature operation test was examined for ohmic electrodes. We confirmed the reliability performance under the following test condition, the current density of $2x10^6$ A/cm^2 at 250 deg-C in nitrogen ambient.

Figure 9 shows the resistance degradation rate for the fabricated ohmic electrodes. After 500 hours test the resistance varied only 6 %. And the RF-stress test was examined under P_3 dB conditions at Vds of 60 V as shown in Fig. 10 [8]. The Idsq was set at 15 mA/mm. Our newly improved collapse-free AlGaN/GaN HEMTs operated at 60 V, and showed no degradation of power and gain over 1000 hours.

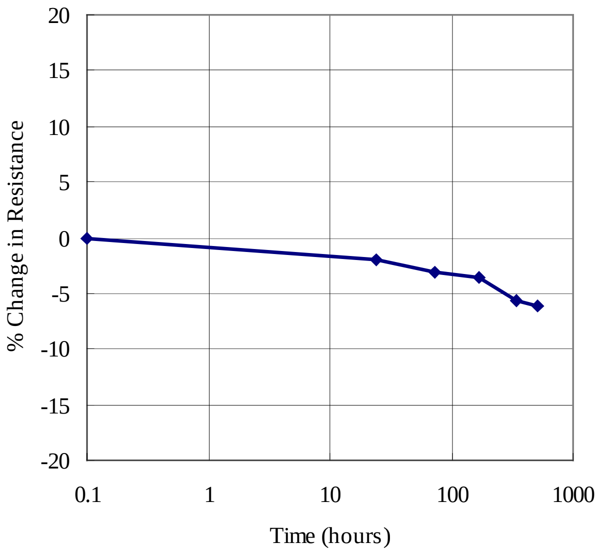

Fig.9 Resistance variation of ohmic electrodes under current density of $2x10^6$ A/cm^2 at 250 deg-C in nitrogen ambient.

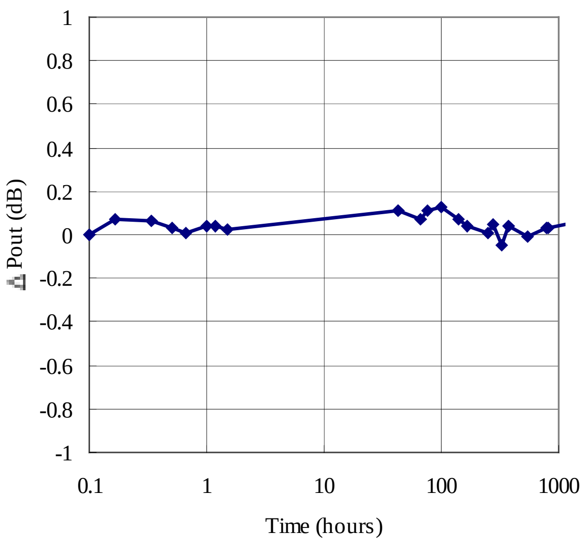

Fig.10 Power characteristics under P_3 dB RF-stress test at 60 V.

CONCLUSIONS

In summary, we fabricated the AlGaN/GaN HEMTs with the surface-charge-controlled structure on a SiC substrate, which exhibits the high uniformity and reliable characteristics. The manufacturability of the aforesaid AlGaN/GaN HEMT structure makes it an attractive candidate for microwave power applications.

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REFERENCES

[1] W.L.Pribble, J.W.Palmour, S.T.Sheppard, R.P.Smith, S.T.Alen, T.J.Smith, Z.Ring, J.J.Sumakeris, A.W.Saxler, and J.W.Milligan, 2002 MTT-S Digest, pp1819-1822, June 2002

[2] Y.Okamoto, Y.Ando, H.Miyamoto, T.Nakayama, T.Inoue and M.Kuzuhara, 2003 MTT-s Tech. Digest, pp225-228, June 2003.

[3] T.Kikkawa et al., 2001 IEDM Tech. Digest, pp585-588, December 2001.

[4] M.Nagahara, T.Kikkawa, N.Adachi, Y.Tateno, S.Kato, M.Yokoyama, S.Yokogawa, T.Kimura, Y.Yamaguchi, N.Hara, and K.Joshin,"2002 IEDM Tech. Digest, December 2002.

[5] T.Kikkawa, M.Nagahara, N.Adachi, S.Yokokawa, S.Kato, M.Yokoyama, M.Kanamura, N.Hara, and K.Joshin, 2003 RF-IC Digest, pp167-170, June 2002.

[6] K.Joshin et al., 2003 IEDM Tech Digest, pp983-985, December 2002.

[7] M.Kanamura et al., Extended abstracts of 2003 Solid State Devices and Materials, pp.916-917, September 2003.

[8] T.Kikkawa ISCS-2004 Extended Abstracts, p136, September 2004.