

High power and high gain AlGaIn/GaN MIS-HEMTs with high-k dielectric layer

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High power n-GaN/n-AlGaIn/GaN metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) with high-k Ta₂O₅ dielectric layer were fabricated on a 3-inch SiC substrate, for the first time. An n-GaN/n-AlGaIn/GaN MIS-HEMTs with 400 V breakdown voltage were obtained by using Ta₂O₅ insulating layer/n-GaN cap-

structure. The single-chip GaN MIS-HEMTs amplifier with a Ta₂O₅ layer operated at 50 V achieve a high output power of 113 W with a linear gain of 16.3 dB at 2.5 GHz. We also investigated the RF stress reliability under the P3dB condition. The fluctuation of output power and drain current was lower than 5% even after 150 h stress test.

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1 Introduction Wireless mobile networks are expected to move up to 4G technologies from 2010. These next generation networks will be needed much higher power efficiency to reduce the increased power consumption, requiring AlGaIn/GaN HEMT to be used at the saturation region. Millimeter wave application also requires high power operation to reduce the size of MMIC. However, forward gate leakage current increases when power amplifier is operated under large input signal condition, creating problems in terms of reliability and amplification characteristics. To improve the forward gate leakage current, many researchers have tried to introduce the insulator between the gate and semiconductor. We also developed an AlGaIn/GaN MIS-HEMT with a SiN/n-GaN structure which can be operated at 60 V with 110 W [1]. A SiN/n-GaN interface has a lower trap density than a conventional SiO₂/i-AlGaIn structure. However, a relatively low dielectric constant of SiN (7.0) caused a decrease of the transconductance (g_m) and a negative shift in the threshold voltage as shown in Fig. 1. In our case, the linear gain of 38.4 mm HEMT amplifier was 12 dB. This value was 4 dB lower than the conventional Schottky gate HEMT. Using a high-k dielectric material as a gate insulator solves these problems. At present, several groups reported the GaN MIS-HEMT with high-k materials and very low gate leak-

age current were obtained [2-4]. However, there are a few reports on the RF power characteristics [3].

In this paper, we presents a fabrication of the AlGaIn/GaN MIS-HEMTs with a Ta₂O₅ dielectric layer and shows the potentialities of GaN based MIS-HEMT for the high power applications. A Ta₂O₅ layer is one of good candidates as gate insulator because it has a relatively high dielectric constant and the band gap almost same to SiN. In addition, coefficient of thermal expansion is close to the value of SiN.

2 Experimental A cross-section of the AlGaIn/GaN MIS-HEMT used in this study is shown in Fig. 2. An n-GaN/n-AlGaIn/i-GaN HEMT structure was grown on a 3-inch SiC substrate by metal organic chemical vapour deposition (MOCVD). To suppress the frequency dispersion related surface instability, we used a slightly n-type doped GaN cap layer [5]. The processing started with device isolations by ion implantation. The source/drain and gate electrodes were composed of Ti/Al and Ni/Au, respectively. Ti/Al ohmic electrodes were annealed at 550 °C for 30 s in N₂ ambient to keep the surface smooth. Recessed ohmic technology was used to reduce the ohmic contact resistance [6]. An n-type doped GaN cap layer was removed by Cl₂ reactive ion etching. The specific contact resistance

was $5 \times 10^{-6} \Omega \text{cm}^2$. Prior to gate formation, a 40 nm thick Si_3N_4 layer was deposited using plasma enhanced chemical vapour deposition (PE-CVD). SiN below the gate region was selectively removed by RIE. Next, 10 nm thick Ta_2O_5 layer was sputtered and the gate electrode was formed by the evaporation of Ni/Au and standard lift-off technique. The typical gate length was 0.8 μm . Then, Au air-bridge processes were used to form the complete AlGaIn/GaN power HEMT.

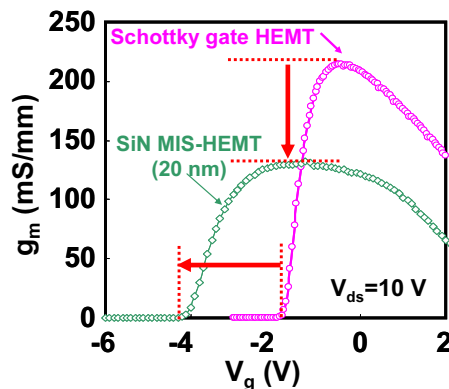


Figure 1 Problems of GaN MIS-HEMT with a SiN insulator.

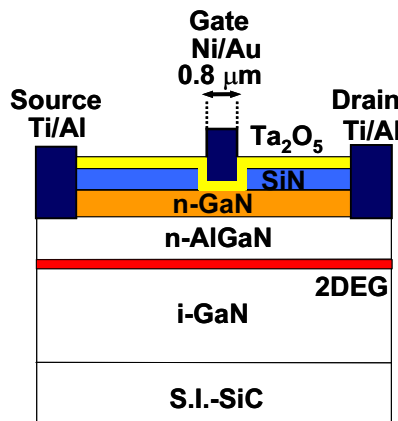


Figure 2 Cross section of AlGaIn/GaN MIS-HEMT.

3 Results and discussion

3.1 DC characteristics Figure 3 is the result of C–V measurements for the n-GaN/n-AlGaIn/GaN MIS-HEMT with Ta_2O_5 dielectrics. Capacitance of $V = 0$ to -2 V is determined by $\text{Ta}_2\text{O}_5/\text{n-GaN}/\text{n-AlGaIn}$ layers between 2DEG and the gate electrode. The absence of any significant shift in C–V curve between the positive and negative sweep indicates that the interface trap is insignificant. Figure 4(a) show the typical I–V characteristics for the Ta_2O_5 based GaN MIS-HEMT. The maximum drain current was 600 mA/mm at the gate voltage of 2 V. A negligible current reduction was observed between the low (10 V) and high (50 V) drain bias sweep in Fig. 4(a). We also investigated pulsed I–V characteristics to assess the interface quality as shown in Fig. 4(b). Bias points were varied to

evaluate the effect of trap on Ron and Gd. Fig. 4(b) indicates that the fabricated MIS-HEMTs have good interface quality between the insulator and n-GaN capping layer. The $g_m - V_g$ characteristics are shown in Fig. 5. The peak transconductance was 200 mS/mm at a drain bias voltage of 10 V. Threshold voltage was -2.1 V. Good pinch-off characteristics were observed. These results are attributed to the high dielectric constant of Ta_2O_5 . Forward gate leakage current at the gate voltage of 1.5 V of the Ta_2O_5 MIS-HEMT was six orders of magnitude lower than that for a Schottky gate HEMT (Fig. 6(a)). The value of the forward gate current for the Ta_2O_5 MIS-HEMT is enough small to utilize this technology for a base station application. Reverse gate leakage currents at gate-drain voltage of 100 V for Schottky gate HEMT and Ta_2O_5 MIS-HEMT are 1.6 $\mu\text{A}/\text{mm}$ and 10 nA/mm, respectively as shown in Fig. 6(b). The breakdown voltage of the Ta_2O_5 MIS-HEMT was 400 V.

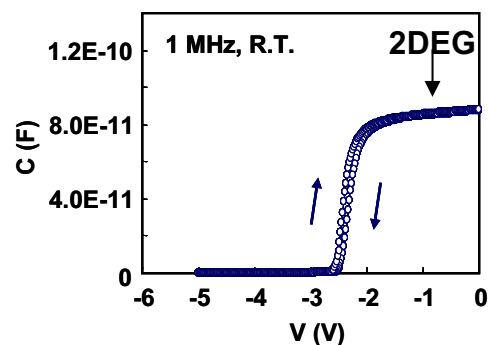


Figure 3 C–V curve of GaN MIS-HEMT with Ta_2O_5 insulator.

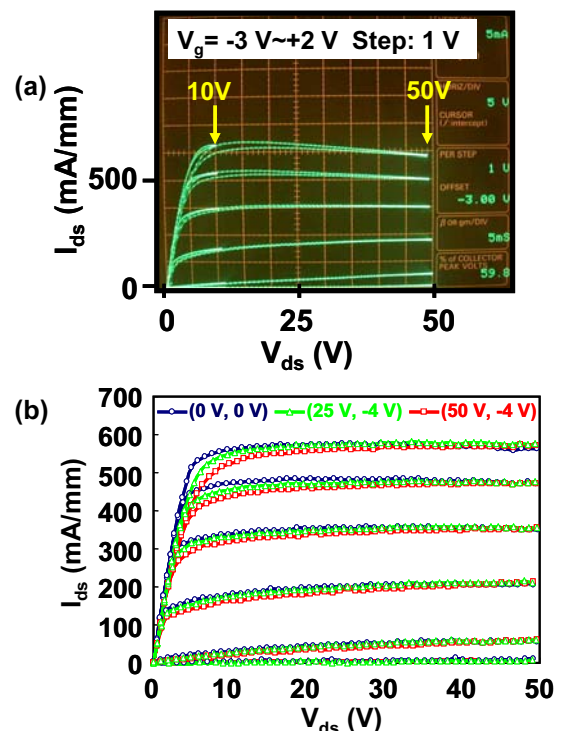


Figure 4 Typical DC characteristics for GaN MIS-HEMT (a) curve tracer (b) pulsed I–V.

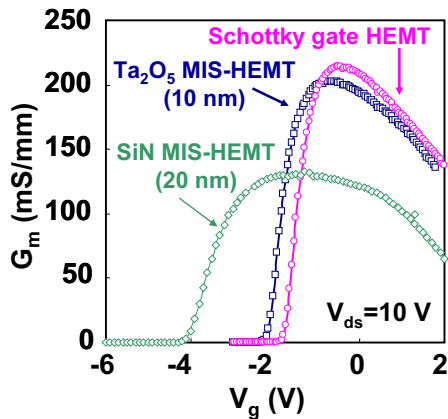


Figure 5 g_m - V_g characteristics of AlGaIn/GaN MIS-HEMT.

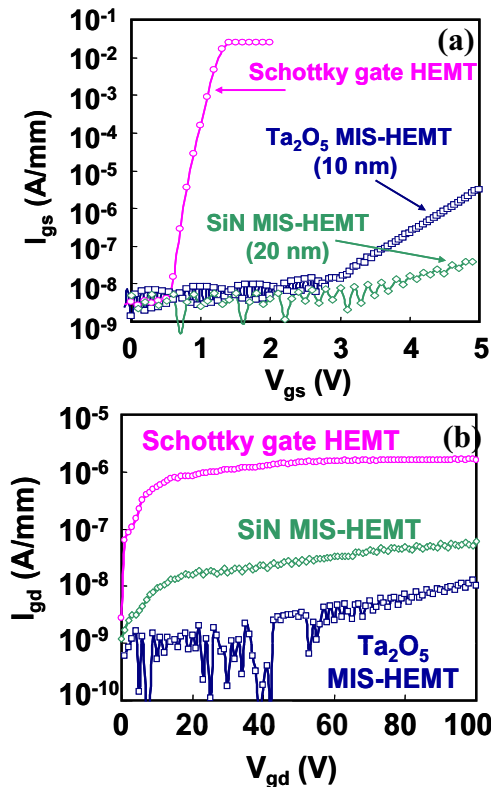


Figure 6 Forward (a) and reverse (b) gate leakage characteristics of AlGaIn/GaN MIS-HEMT.

3.2 High power characteristics We carried out on-wafer power measurements for the high-k MIS-HEMT. A drain voltage is 70 V and devices are biased into deep class-AB. The gate width and gate length are 1 mm and 0.8 μm , respectively. A measurement frequency is 2 GHz. The results from on-wafer power measurements are shown in Fig. 7. We obtained a P_{sat} of 9.4 W/mm with a peak power added efficiency (PAE) of 62.5% and a linear gain of 23.5 dB. The gate leakage current during the measurement are shown in Fig. 8. The MIS-HEMT structure completely suppresses gate leakage current under large input

power. Next, the high-k MIS-HEMT chip was mounted on a conventional metal/ceramic package. The gate periphery is 38.4 mm with a unit gate width of 400 μm . We achieved a high output power of 113 W with a linear gain of 16.3 dB at 2.5 GHz as show in Fig. 9. The gain of 16.3 dB is 4 dB higher than that of GaN MIS-HEMT with SiN [1].

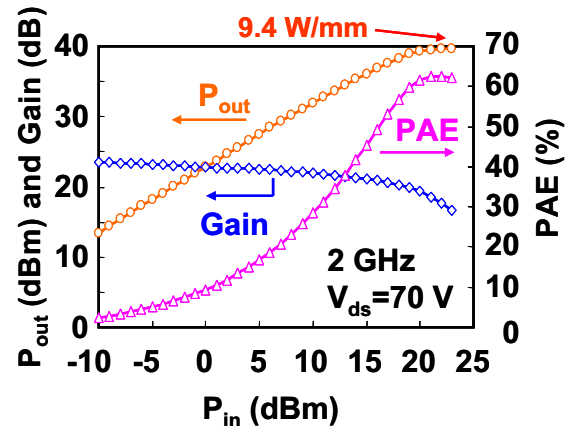


Figure 7 Result of on-wafer power measurement for 1mm MIS-HEMT.

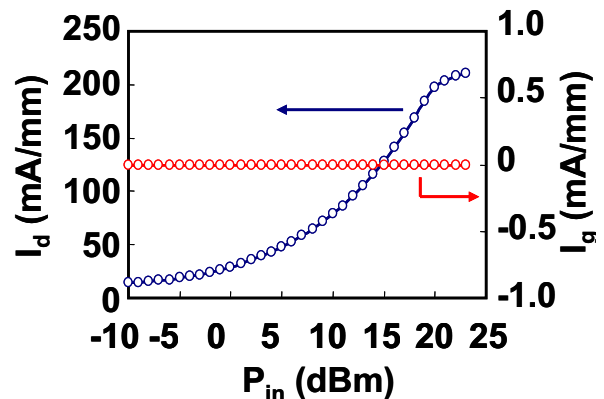


Figure 8 Gate leakage current during power measurement for 1 mm MIS-HEMT.

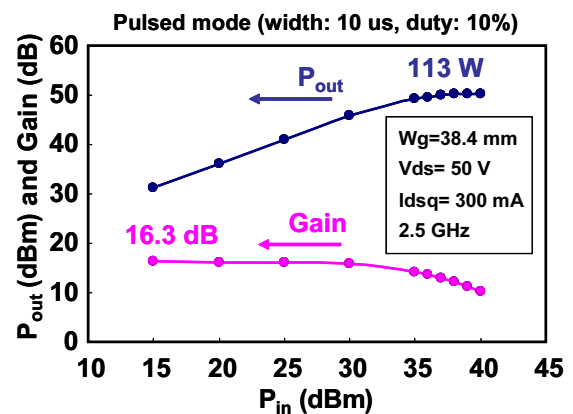


Figure 9 High power performances for 38.4 mm MIS-HEMT.

3.3 RF stability We also investigated the 1 mm MIS-HEMT device power stability. Figure 10 is the results of the RF-stress test under P3dB operation at room temperature at the drain voltage of 50 V. The variation of output power was lower than 0.5 dB even after 150 h stress test, suggesting the initial stability of MIS-HEMT.

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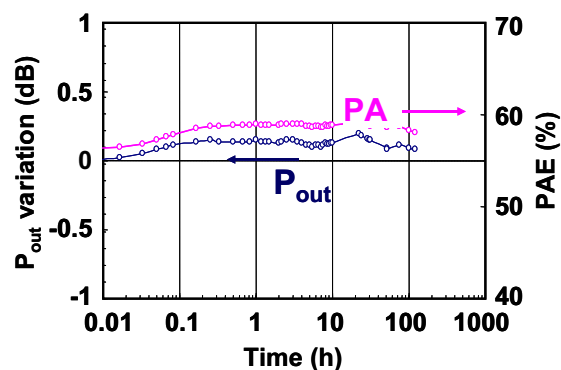


Figure 10 RF power stability for 1 mm MIS-HEMT.

4 Conclusion We fabricated the AlGaIn/GaN MIS-HEMT with the high-k Ta_2O_5 layer, for the first time. The devices showed the low gate leakage current and small current collapse. We carried out the power measurements for the 38.4 mm MIS-HEMT devices. Our MIS-HEMT exhibited the P_{out} of 113 W and linear gain of 16.3 dB at the drain voltage of 50 V at the frequency of 2.5 GHz. We also investigated the RF power stability for the MIS-HEMT and we confirmed that no degradation of the output power and drain current for the fabricated MIS-HEMT under P3dB stress test.

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