AlGaN/GaN MIS HEMT with AlN Dielectric

Chen Tangsheng,Jiao Gang,Li Zhonghui,Li Fuxiao,Shao Kai,Yang Naibin

Nanjing Electronic Devices Institute, P.O.Box 1601,Nanjing 210016, P.R.China
Email:chentsh@vip.sina.com, Phone:+862586858430

Keywords: AlGaN/GaN, HEMT, MIS, AlN, Microwave Power Transisitor

Abstract

AlGaN /GaN MIS HEMT with AlN dielectric which is deposited by reactive sputtering is reported for the first time in this paper. With the addition of gate recess and field plate configuration, the developed 0.4 µm AlGaN/GaN MIS HEMT reveals one order reduction in the gate leakage current up to -80 V drain-gate bias compared to the recessed Schottky gate HEMT and shows a current gain cut-off frequency and a maximum oscillation frequency of 30 GHz and 60 GHz respectively. The multifinger device with 1 mm gate width delivers 6.1 W output power with 7.8 dB power gain and 40.3 % power-added efficiency at frequency of 8 GHz and drain bias of 30 V.

INTRODUCTION

There is no doubt that AlGaN/GaN high electron mobility transistors (HEMTs) will be next generation microwave power devices for their excellent high power handling capability in high frequency operations. Many approaches have been used to improve the power performance and reliability of the devices. Among of them, field plate configuration can be used to reduce the electric field at the gate edge under pinch-off conditions and to release the channel constriction which occurs under open channel conditions[1-2]. So field plate configuration proves to be effective for the improvement of the power performance and also the reliability of AlGaN/GaN HEMTs because the negative charges which constrict device channel under open channel condition may lead to power degradation. Gate leakage current is recognized as a main factor causing dc and RF parameters degradation under large input signals, especially at high channel temperatures. For this reason, AlGaN/GaN based metal-insulator-semiconductor high electron mobility transistors (MIS HEMTs) in which the gate leakage current can be decreased dramatically have been reported [3-4]. Otherwise, gate recess which is widely used in GaAs FETs processing to increase the breakdown voltage of FETs and to screen the channel of FETs from surface potential fluctuation has also been used for the same sakes and proves to be effective too [5-6].

Nowadays, field plate configuration combined with gate recess or with MIS configuration have been widely used in R&D of AlGaN/GaN HEMTs[2-3] [6]. For MIS configuration without gate recess, normally a relatively thin barrier layer is designed to get a suitable pinch-off voltage and a relative high transconductance and it is difficult to get high maximum drain current[4]. In AlGaN/GaN MIS HEMTs, a very thin layer of SiO_2 [3]or SiN[4] deposited by plasma-enhanced chemical vapor deposition (PECVD) is often used as the insulating dielectric. It is difficult to get a good thickness control of around 10nm dielectric film deposited by PECVD. In this paper, a AlGaN/GaN MIS HEMT combined with gate recess is reported for the first time. As the gate insulator, AlN deposited by reactive sputtering demonstrates higher permittivity compared to SiN and SiO_2, and shows good thickness controlability through the sputtering process. With the addition of field plate configuration, AlGaN/GaN MIS HEMTs with AlN dielectric reveals to be more promising for the high microwave power application.

PROCESS OF THE DEVICES

The AlGaN/GaN MIS HEMT developed in this study is schematically illustrated in Fig.1. The AlGaN/GaN heterostructure was grown on the SiC substrate by metal–organic chemical vapor deposition (MOCVD) using a Thomas Swan close coupled showerhead reactor. All epitaxial layers were not intentionally doped and the Al composition of AlGaN was chosen to be 0.25. Lehighton

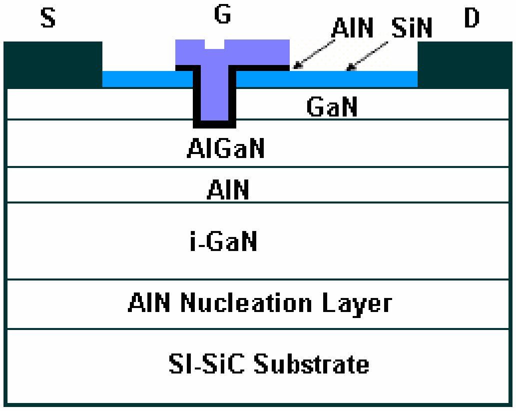

Fig.1 Schematic cross-section of the developed AlGaN/GaN MIS HEMT with AlN dielectric

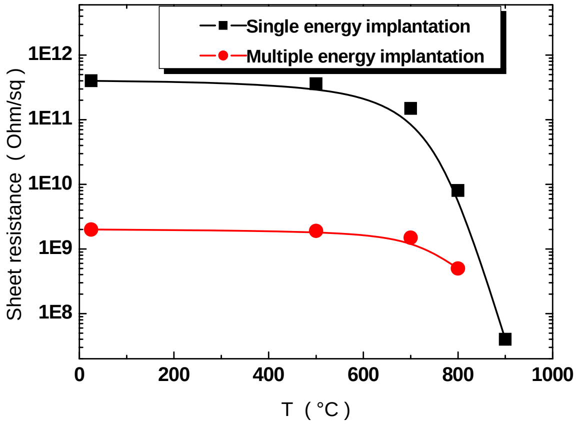

Fig.2 The variation of isolation resistance with annealing temperature

measurements indicated a sheet risistance of about 350 Ohm/sq. The processing started with Ohmic contact. Source and drain ohmic electrodes were formed by evaporating Ti/Al/Ni/Au [7], which was then alloyed using rapid thermal annealing at 870 ℃. The contact resistance evaluated by transmission-line matrix (TLM) measurements was about 0.5 Ohm-mm. Then, the sample was passivated with a layer of SiN deposited by PECVD. Following that, Boron ions implantation was used to realize the active layer isolation for the first time. An isolation sheet resistance of 10^{11} Ohm/sq was achieved through optimizing the implanting energies and doses. The high resistance of the implanted region keeps stable up to 700 ℃ annealing. The variation of isolation resistance with annealing temperature was shown in Fig.2. Otherwise, An increase in the breakdown voltage and an increase in unity current gain cutoff frequency and maximum oscillation frequency have been found for the B^+ implantated isolation devices compared to the RIE etched mesa isolated devices. After that,an e-beam lithography system was used to define the foot of the submicron gates. After a gate footprint was opened through the SiN film, gate recess etching was performed using an ICP with BCl_3/Cl_2 to recess the GaN cap layer and some of the AlGaN barrier layer. Following gate recess, a second e-beam lithography defined the top of the gates and also the dimension of the field plate. PMAA-PMMA bilayer resist was used in this second e-beam lithography. Prior to gate metal deposition, a 8 nm thick AlN film was deposited by active sputtering and then a Ni/Au was deposited by e-beam evaporation in succession. After lift-off of the trilayer film, the device was again covered with a SiN film as surface passivation and was provided with a standard Au-plated airbridge process to complete a multifinger FET. In order to identify the effect of the AlN film on the device performance, recessed Schottky gate AlGaN/GaN HEMTs have been completed at the same time. Except with or without AlN film, there in no difference between the recessed Schottky gate AlGaN/GaN HEMT and the MIS HEMT.

DC PERFORMANCE OF THE DEVICES

Fig. 3 shows drain current-voltage (I-V) characteristics for a recessed Schottky gate AlGaN/GaN HEMT and a MIS HEMT with AlN dielectric. The devices have a gate width of 200 µm and a gate length of 0.4 µm and field plate of 0.6 µm. Two types of FETs have almost the same maximum drain current of about 1.3 A/mm at a gate voltage of 2 V with good pinch-off characteristics. Results of Fig.3 shows the advantage in maximum drain current for the combination of MIS configuration with gate recess. Transconductance characteristics for two types of FETs is illustrated in Fig.4. With the insertion of a thin layer of AlN, the pinch-off voltage was changed from -3.5 V for the recessed Schottky gate AlGaN/GaN HEMT to -5.5 V for the MIS HEMT. Correspondingly, the maximum transconductance was changed from about 320 mS/mm to about 260 mS/mm. As shown in Fig.5, the turn-on voltage for the MIS HEMT was obviously greater than that of the recessed Schottky gate AlGaN /GaN HEMT. AlGaN/GaN HEMTs demonstrate many times higher output power density compared to GaAs FETs. Correspondingly, similar higher input power density is required. So it is necessary to increase the gate

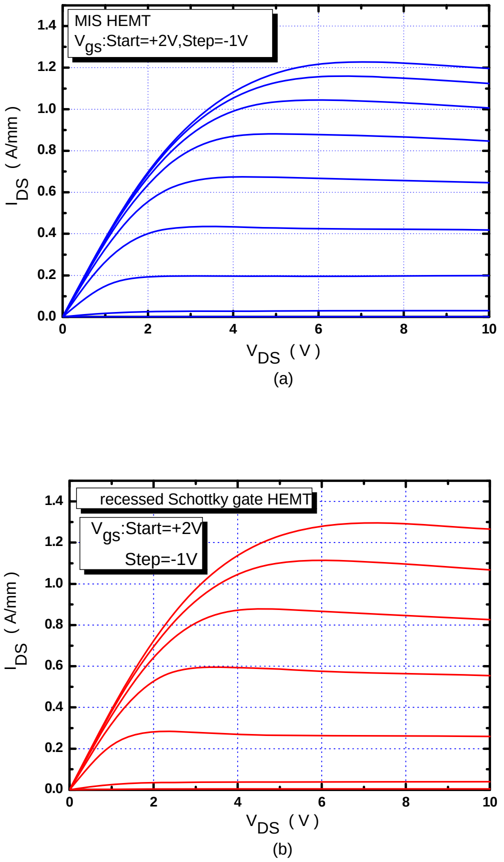

Fig.3 I-V curves for the recessed Schottky gate AlGaN/GaN HEMT (a) and the MIS HEMT (b)

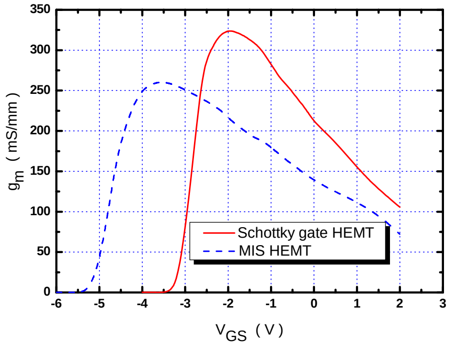

Fig.4 Transconductance characteristics for the recessed Schottky gate AlGaN/GaN HEMT and the MIS HEMT

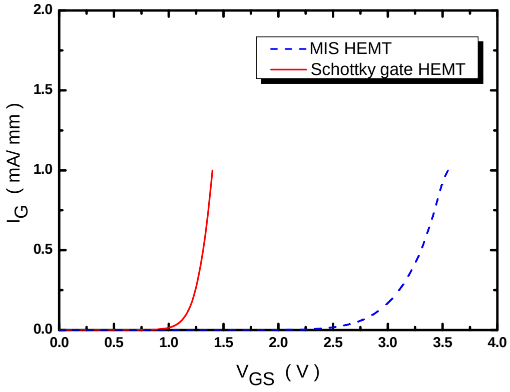

Fig.5 Forward gate currents for the recessed Schottky gate AlGaN/GaN HEMT and the MIS HEMT

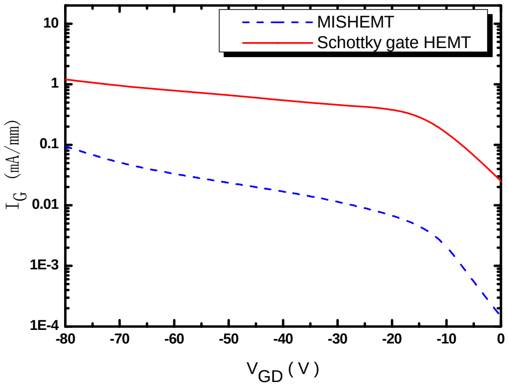

Fig.6 Reverse gate leakage currents for the recessed Schottky gate AlGaN/GaN HEMT and the MIS HEMT

turn-on voltage to avoid the forward gate current for AlGaN/GaN HEMTs. Also reverse gate leakage currents at gate-drain bias of -80 V for the recessed Schottky gate AlGaN/GaN HEMT and the MIS HEMT were 1.2 mA/mm and 95 µA/mm, respectively. Fig. 6 compares gate-drain reverse I-V characteristics for those two types of FETs. Greater than 100 V breakdown voltage has been got for AlGaN/GaN MIS HEMT and it is necessary for high voltage operation.

RF PERFORMANCE OF THE DEVICES

Small-signal microwave performance was characterized on wafer using HP 8510C vector network analyzer and Cascade probe station with ground-signal-ground RF probes. Fig.7 shows the measured |h21| and MSG versus frequency for the developed AlGaN/GaN MIS HEMT revealing f_T of 30 GHz and f_{max} of 60 GHz when biased at 10 V. The frequency performance of the Schottky gate AlGaN/GaN HEMT has been compared and nearly the same results have been got.

A multifinger AlGaN/GaN MIS HEMT with a gate width of 1 mm was attached into a metal-ceramic package and its power performance was evaluated at 8 GHz with external input and output matching circuits. The input impedance was adjusted to maximize the linear gain and the output impedance was matched to maximize the output

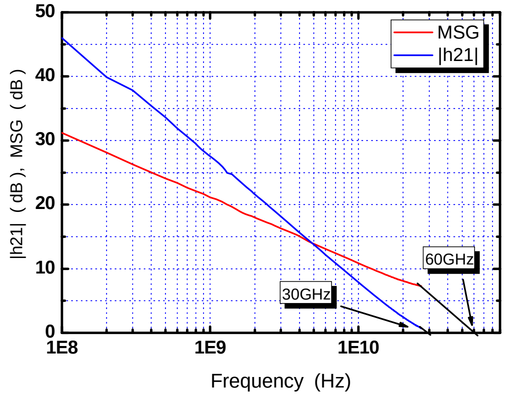

Fig.7 Measured h21 and MSG versus frequency for the developed AlGaN/GaN MIS HEMT showing f_T of 30 GHz and f_{max} of 60 GHz when biased at 10 V.

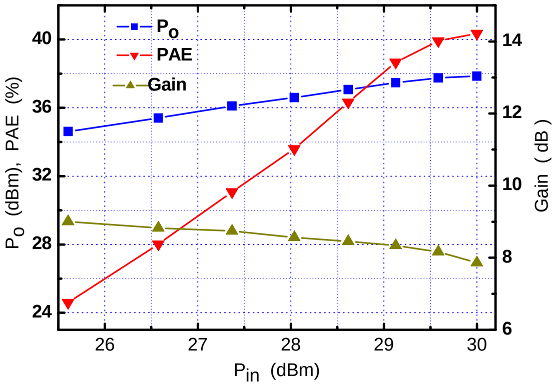

Fig.8 Output power, power gain and PAE for the 1mm-gate-width MIS HEMT as a function of input power at V_{ds}=30V

power. Fig. 8 exhibits continuous wave (CW) output power, power gain and power-added effiency as a function of input power. The developed 1mm gate width AlGaN/GaN MIS HEMT delivers 6.1 W output power with 7.8 dB power gain and 40.3% power-added efficiency at frequency of 8GHz and Vds=30V.

CONCLUSIONS

AlGaN/GaN MIS HEMT with AlN dielectric which is deposited by reactive sputtering has been developed. B^+ implantation was used to realize the active layer isolation for the first time. The isolation sheet resistance of 10^{11} Ohm/sq has been achieved and the high resistance of the implanted region keeps stable up to 700 ℃ annealing. With the addition of the gate recess and the field plate configuration, the developed 0.4 µm AlGaN/GaN MIS HEMT exhibits one order reduction in the gate leakage current up to -80 V drain-gate bias compared to the recessed Schottky gate HEMT. The Schottky gated HEMT and MIS-HEMT show almost the same current gain cut-off frequency and maximum oscillation frequency. The multifinger device with 1 mm gate width delivers 6.1 W output power with 7.8 dB power gain and 40.3% PAE at frequency of 8 GHz and $V_{ds} = 30$ V. Further works are being carried out to improve the power performance and to evaluate the realiability of the AlGaN/GaN MIS HEMT with AlN dielectric.

ACKNOWLEDGEMENTS

The authors would like to thank the support from the National Key Laboratory of Monolithic Integrated Circuits and Modules to this project. Additionally, Thanks are given to Ren Chunjiang,Li Xiao,Xu Xiaole and Geng Tao for their processing assitance.

REFERENCES

[1] Y.-F. Wu, A. Saxler, M. Moore, et al.,30 W/mm GaN HEMTs by field plate optimization. IEEE Electron Device Lett., **25**, pp. 117–119, 2004.

[2] Yasuhiro Okamoto, Yuji Ando, Tatsuo Nakayama, et al., High-Power Recessed-Gate AlGaN–GaN HFET With a Field-Modulating Plate. IEEE Electron Devices, **51**, pp. 2217-2222, 2004.

[3] V. Adivarahan, J. Yang, A. Koudymov, G. Simin and M. Asif Khan, Stable CW Operation of Field-Plated GaN-AlGaN MOSHFETs at 19 W/mm. IEEE Electron Device Lett., **26**, pp. 535-537, 2005.

[4] M. Kanamura, T. Kikkawa, et al., An Over 100 W n-GaN/n-AlGaN/GaN MIS-HEMT Power Amplifier for Wireless Base Station Applications. IEDM Tech. Digest, pp23-2, 2005.

[5] T. Palacios, A. Chakraborty, S. Rajan, et al., High-Power AlGaN/GaN HEMTs for Ka-Band Applications. IEEE Electron Devices, **51**, pp. 2217-2222, 2004.

[6] J. S. Moon, Shihchang Wu, D. Wong, et al., Gate-Recessed AlGaN–GaN HEMTs for High-Performance Millimeter-Wave Applications. IEEE Electron Device Lett., **26**, pp. 348-350, 2005.

[7] Chen Tangsheng, Jiao Gang,Xu Fangshi,et al., 1mm Gate Width X-Band 6 W Output Power AlGaN/GaN HEMT. IC-China 2005 & Beijing International Microelectronics Symposium Album, pp.241-244, 2005.(in Chinese)

ACRONYMS

AlGaN: Aluminum Gallium Nitride
GaN: Gallium Nitride
HEMT: High Electron Mobility Transistor
GaAs: Gallium Arsenide
SiC: Silicon Carbide
AlN: Aluminium Nitride
FET: Field Effect Transistor
MIS: Metal-Insulator Semiconductor
TLM: Transmission-Line Matrix
PECVD: Plasma-Enhanced Chemical Vopor Deposition
RIE: Reactive-Ion Etching
ICP: Inductively Coupled Plasma
PAE: Power-Added Efficiency