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High Breakdown Voltage and Low Thermal Effect Micromachined SOI AlGaN/GaN HEMTs

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Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) have attracted a great interest for next generation of power electronics due to its high power, high frequency, and high temperature capability [1], [2]. For reducing the cost and large size availability, the silicon is widely used for the AlGaN/GaN HEMTs substrate [3]. Recently, Lu et al. [4] realized a substrate transfer technology from Si to glass. Srivastava et al. [5] demonstrated a silicon substrate removal (S.R.) technology, and the breakdown voltage is over 1100 V. It is suggested the maximum breakdown voltages of the GaN on Si HEMTs are limited by the Si substrate because of the lower silicon electrical field strength (0.3 MV/cm) [6], [7]. However, the obvious current reducing phenomenon caused by the self-heating effect after substrate removal or transfer is observed.

In this work, a novel technology using Si substrate removal with semiconductor on insulator (S.O.I.) technology is demonstrated and the low thermal effect and high breakdown voltage are achieved.

Device Structure and Fabrication

The process flows of S.O.I. technology is shown in Fig. 1. The sample used in this work was a commercial AlGaN/GaN HEMT wafer grown by MOCVD on (111) silicon substrate. The epitaxial structure includes a 1.8 μm buffer, a 0.8 μm GaN channel layer, and a 18 nm AlGaN barrier layer. The wafer demonstrated a sheet resistance of 396 ohm/square, a sheet charge density of 1.03×10^{13} cm^{-2} together with a Hall mobility of 1534 cm^2/V-s at 300K.

The device size is 2×100 μm and was processed by conventional optical lithography and lift-off process. The ohmic contacts were realized by using Ti/Al/Ni/Au followed by a 850 ^{o}C, 30 sec RTA annealing in N_2 ambient. To define an active region, high density coupled plasma was used for 200 nm depth mesa etching. Then Ni/Au was deposited by electron-beam evaporator for 1 μm-long gate electrode. The distances between gate to source and drain both are 3μm. A 20/300 nm Ti/Au was deposited for interconnection and probe pads. Then, a 300 nm SiO_2 was deposited using plasma enhance chemical vapor deposition (PECVD) chamber at 200^{o}C for device passivation layer. For the Si substrate removal approach, the substrate is locally etched from the backside using SF_6 plasma in RIE. Finally, a 300 nm-SiO_2 was deposited using PECVD and a 10 μm-Cu metal was deposited by electron-beam evaporator.

Experimental Results

The Fig. 2 shows the I_{DS}–V_{GS} and g_m–V_{GS} characteristics of conventional, S.R., and S.O.I. devices, respectively. An obvious current reducing phenomenon caused by the self-heating effect is observed for S.R. device. However, conventional and S.O.I. devices do not display this phenomenon. It is believed that the 10 μm-Cu metal eliminates the self-heating effect. The results of Fig. 2 also corresponded to the C–V curves shown in inset of Fig. 2. The Fig. 3 presents the I_{DS}–V_{DS} characteristics of three devices. The drain current of the S.R. device smaller than the conventional and S.O.I. devices, which is mainly due to the self-heating effect. But this self-heating effect does not be occurred in S.O.I device, due to the self-heating effect eliminate by a 10 μm-Cu metal.

The Figure 4 exhibits the off-state breakdown characteristics of three devices at $V_{GS} = -5$. The breakdown measurements were carried out using the Keithley 2410 system. The off-state breakdown voltage (V_{BK}) is defined as the voltage at which a leakage current of 1 mA/mm flows between two ohmic contacts. As shown in Fig. 4, the V_{BK} is 169, 382 and 326 V for conventional, S.R. and S.O.I., respectively. The S.O.I. device presents a high V_{BK} which is comparable with S.R. device. The temperature dependent characteristics of maximum drain current for three devices from 25 ^{o}C to 125 ^{o}C are shown in Fig. 5. It can be concluded that the S.O.I. technology significantly eliminates the self-heating effect which caused by substrate removal. The Fig. 6 exhibits the low frequency noise (LFN) measurement of three devices at four different biases. As shown in Fig. 6, the LFN performance of S.R. and S.O.I. device is much lower than the conventional device due to remove the substrate and also remove the traps of substrate.

Conclusion

We have successfully demonstrated the significant enhancement of V_{BK} and eliminated the self-heating effect by S.O.I. technology. A V_{BK} of 326 V has been measured for a 3 μm distance between gate to drain. The temperature dependent characteristics shows a lower self-heating effect for S.O.I. device. The LFN performance of S.O.I. presents a lower noise spectrum due to remove the traps of substrate.

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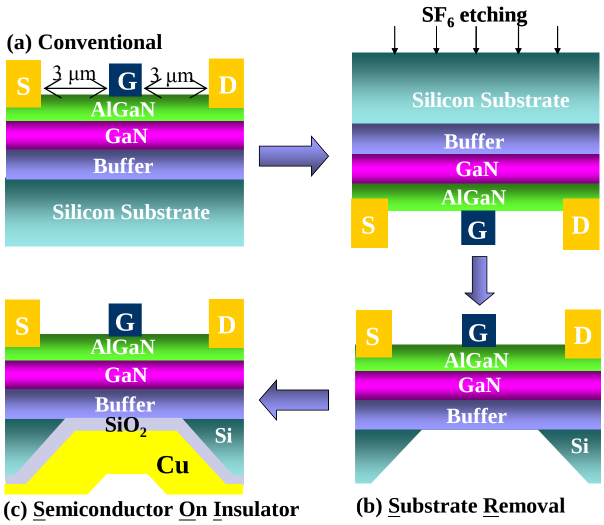

Fig.1. Process flows of the semiconductor on insulator technology. (a) Conventional AlGaN/GaN HEMT on Si substrate. (b) Substrate removal (S.R.). (c) Semiconductor on insulator (S.O.I.).

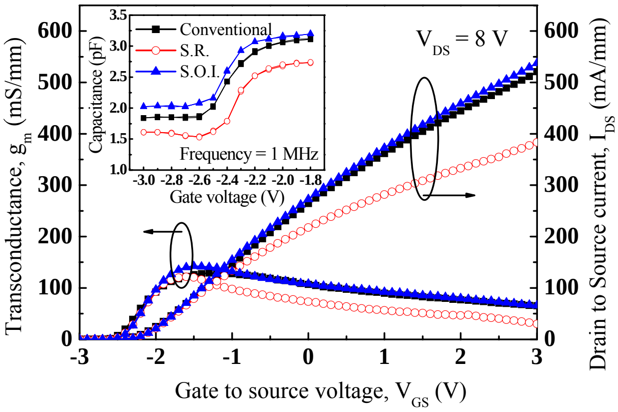

Fig.2. I_{DS}—V_{GS} and g_m—V_{GS} characteristics of three devices at V_{DS} = 8 V. The inset shows the C—V curve of three devices at 1 MHz.

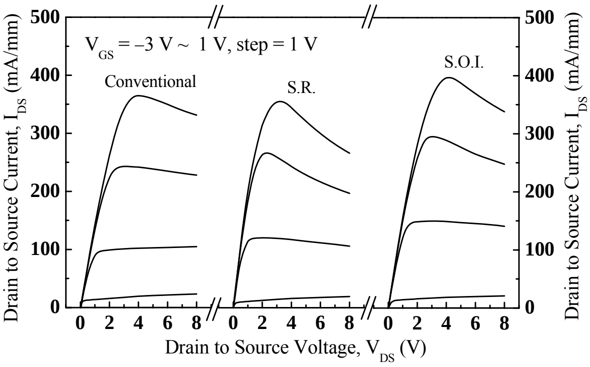

Fig.3. I_{DS}—V_{DS} characteristics of three devices.

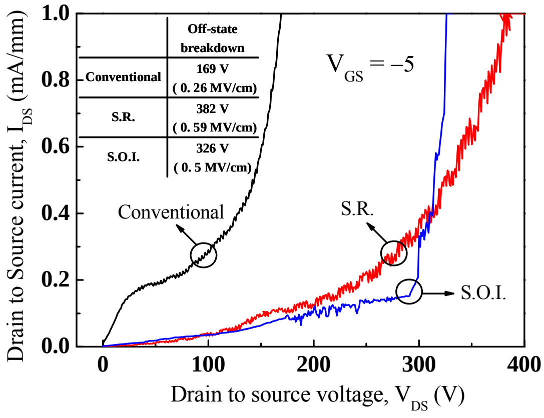

Fig.4. Off-state breakdown characteristics of three devices at V_{GS} = –5

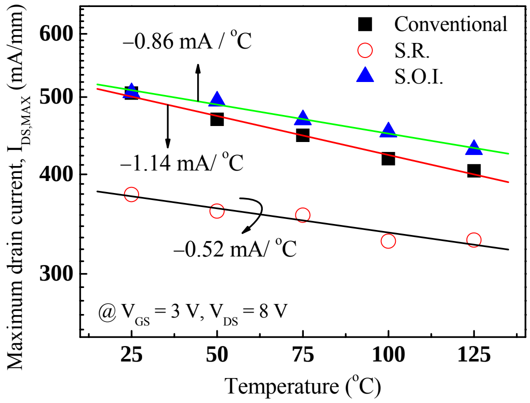

Fig.5. Temperature dependent characteristics of maximum drain current for three devices from 25 °C to 125 °C.

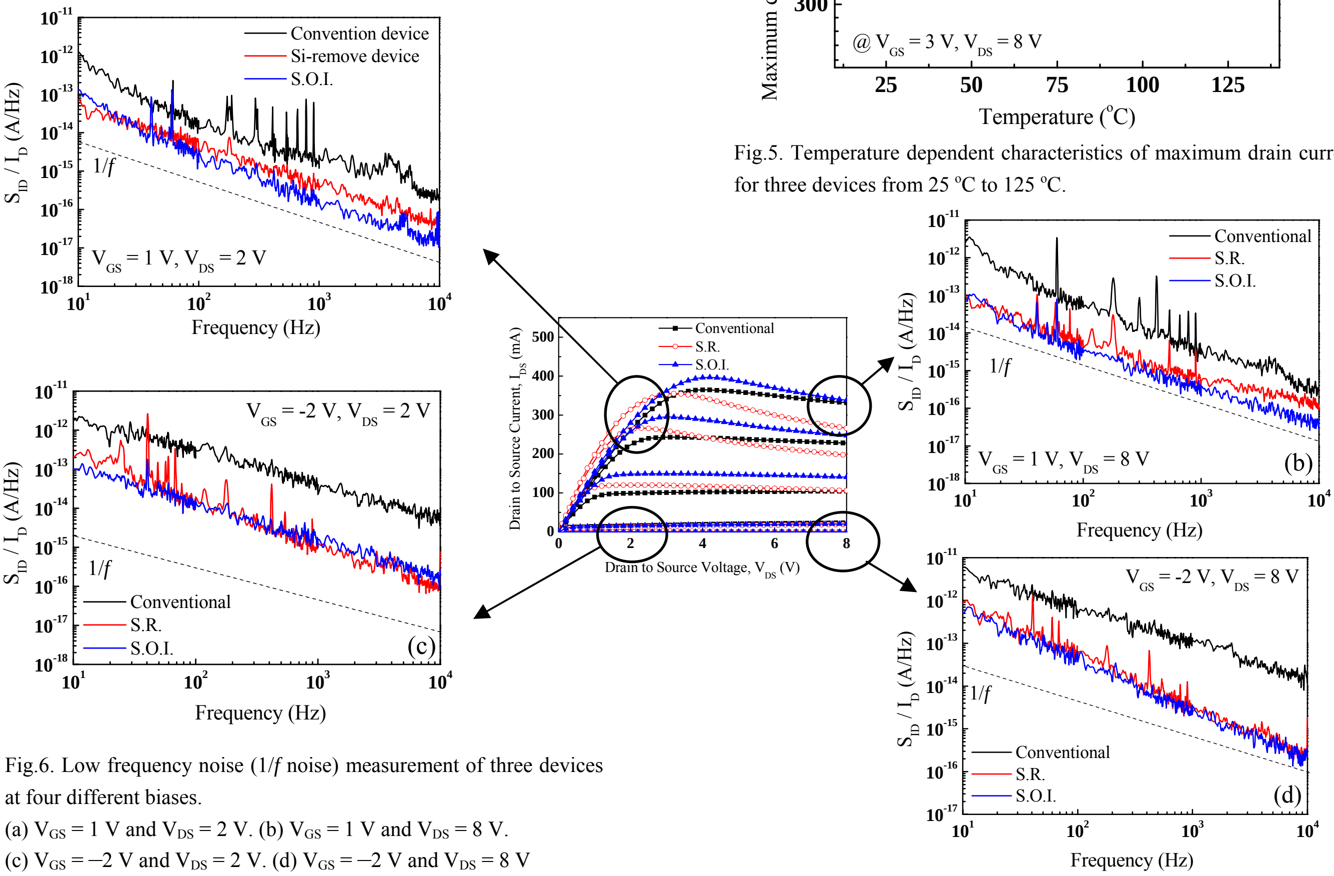

Fig.6. Low frequency noise (1/*f* noise) measurement of three devices at four different biases.

(a) V_{GS} = 1 V and V_{DS} = 2 V. (b) V_{GS} = 1 V and V_{DS} = 8 V.

(c) V_{GS} = –2 V and V_{DS} = 2 V. (d) V_{GS} = –2 V and V_{DS} = 8 V