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The High Temperature Thermally Treated SiN_X Passivation of AlGaN/GaN HEMT using Remote PECVD

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1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) on Si substrate have received much attention for high-frequency and high-power applications. But the larger lattice and thermal expansion coefficient mismatches between Si and GaN, the growth of AlGaN/GaN on Si can produce a higher dislocation density and the possible generation of cracks [1]. And it might have more severe surface trap effects than AlGaN/GaN heterostructures using sapphire or SiC substrate. The surface passivation is one of the most important process of AlGaN/GaN HEMT on Si, for its reduction of the current collapse. Generally the SiO_2 film or the SiN_X film was used for the surface passivation of the GaN devices. And the SiO_2 film, thermally treated at high temperature (1050 °C, 30 s), reduced surface trap effects more effectively than the non-treated [2]. But the SiN_X passivation was commonly used for high power and high-frequency AlGaN/GaN devices.

So in this paper, we studied the high temperature thermally treated SiN_X passivation of AlGaN/GaN HEMT on Si substrate.

2. Epi-structure and Process of AlGaN/GaN HEMTs

$Al_{0.26}GaN$/GaN HEMTs with TLM patterns (ungated devices) and Hall patterns were fabricated on a hetero-structure grown by NITRONEX on a Si substrate. The structure is shown in Fig.1.

Two types of 0.4 μm HEMTs were fabricated. First type used the conventional SiN_X passivation process. The devices were isolated by inductive coupled plasma reactive ion etch using Cl_2. The ohmic contacts were formed using Ti/Al/Ta/Au (200/800 /200/1000 Å) metal system by alloying at 830 °C for 30 s in N_2 ambient (R_C = 0.342 Ωmm). A 0.4 μm gate, defined by E-beam lithography, was formed by Ni/Ir/Au (200/200/3500 Å) evaporation. After the pad metallization, SiN_X film of 1200 Å (R.I. = 1.99 ~ 2.01) was deposited using remote plasma enhanced chemical vapor deposition (RPECVD). And finally post-passivation-annealing was done for 5 minutes at 400 °C in N_2 ambient using furnace for enhanced Schottky gate characteristics.

Second one used the high temperature thermally treated SiN_X passivation process. The first step started SiN_X surface passivation. And other process step was the same as the conventional SiN_X passivation except SiN_X opening using CF_4/O_2 (40/5 sccm) RIE etching and Ti/Al/Mo/Au (150/600/350/500 Å) ohmic metal system (R_C = 0.512 Ωmm) [3]. Because of the initial SiN_X passivation, the surface of AlGaN/GaN heterotructure is protected during other process steps [4] and the SiN_X film was thermally treated during ohmic annealing step at 830 °C for 30 s. The SiN_X film (R.I. = 1.99 ~ 2.01) deposited PECVD is broken with 700 °C, 30 s annealing. The conventional SiN_X passivation film by RPECVD was cracked after 700 °C, 30 s annealing, due to the traces of the previous process steps. And the thermally treated SiN_X passivation film was not broken during the annealing up to 950 °C for 30 s, because of the high quality of SiN_X using PRECVD. With the 830 °C, 30 s thermal treatment, B.O.E. (7:1) etch rate of the SiN_X by RPECVD decreased 40 Å/min from 110 Å/min. And using Ti/Al/Mo/Au ohmic metal system, the inter-mixing of ohmic metal and SiN_X film does not happen during the thermal treatment.

3. Device Performances

The devices were characterized on wafer using Hall measurement, DC and pulsed IV performance using BIO-RAD HL5500PC, 4155A and Accent DiVA 265. The Hall data and the ungated devices IV characteristics are given in Table.I and Fig.2 Using the thermally treated SiN_X, the mobility increased and the current-voltage hysteresis of the ungated devices was reduced [5]. And the dc characteristics are shown in Fig.3. The conventional SiN_X passivated device had V_{TH} = -3.35 V, $g_{m.MAX}$ = 209 mS/mm, I_{DSS} = 501 mA/mm and the thermally treated SiNx passivated one had V_{TH} = -3.5 V, $g_{m.MAX}$ = 199 mS/mm, I_{DSS} = 500 mA/mm. The differences of the dc characteristics think to be caused by the ohmic contact resistance, mobility incensement with the SiN_X thermal treatment and slightly damage at gate SiN_X opening. Finally the pulsed IV characteristics are shown in Fig.4. For the thermally treated SiN_X, the pulsed drain current was increased and the pulsed V_{KNEE} was decreased both $V_{DS.BIAS}$ = 20 V and 30 V. It means that the high temperature thermally treated SiN_X passivation more effectively reduced current collapse than the conventional SiN_X passivation. And the effectiveness of thermally treated SiN_X passivation could be more enlarged with the ohmic contact and SiN_X gate opening optimization.

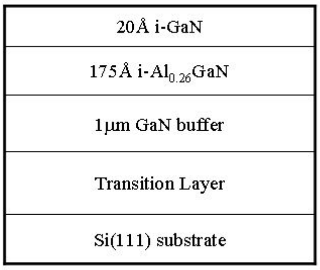


Fig. 1 Schematic of AlGaN/GaN HEMT epi structure

Table.I Hall data

SiN_X 1200Å		R_S [Ohm/sq.]	μ [cm^2/Vs]	N_S [cm^{-2}]
The conventional SiN_X	Initial	783	1650	4.82E12
	After passivation	366	1740	9.78E12
	500°C, 30s	359	1850	9.40E12
	600°C, 30s	350	1860	9.59E12
	700°C, 30s	340	1860	9.75E12
	800°C, 30s	475	1740	7.54E12
		SiN_X cracked : traces of the previous process steps		
The thermally treated SiN_X (830°C, 30s)		324	1920	1.00E13

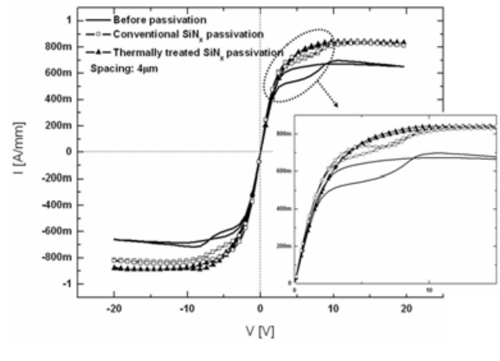
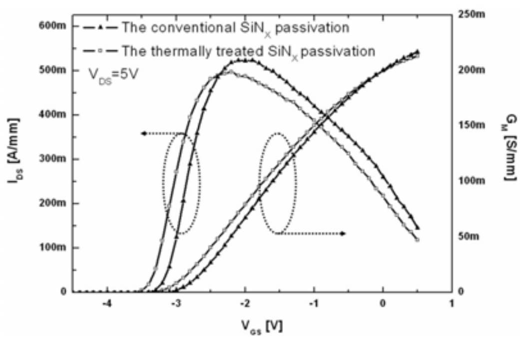


Fig. 2 IV hysteresis of the ungated devices



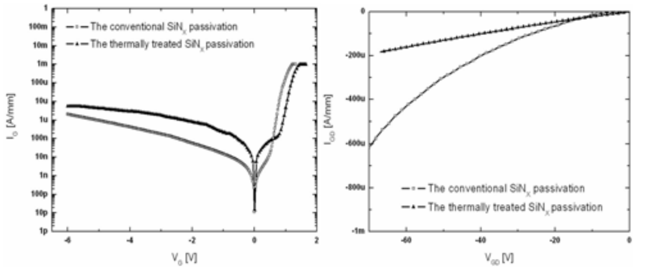


Fig. 3 DC Characteristics

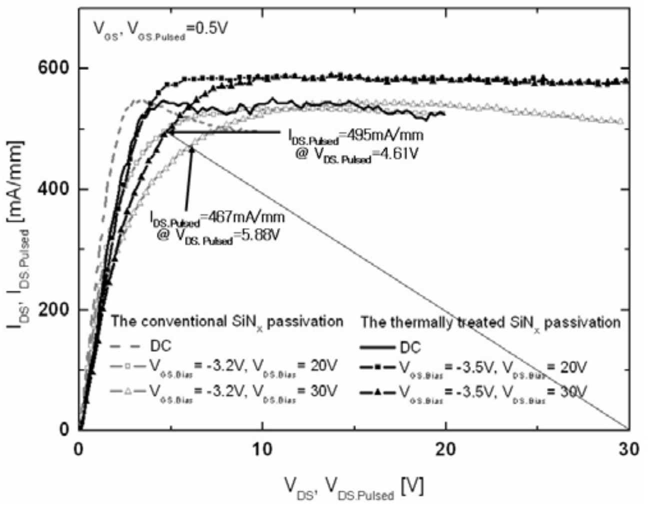


Fig. 4 Pulsed IV characteristics

3. Conclusions

In this paper, we studied the high temperature thermally treated SiN_X passivation of AlGaN/GaN HEMT on Si substrate. With the 830 °C, 30 s thermally treated SiN_X passivation, the mobility was increased. And the current-voltage hysteresis of the ungated devices and the pulsed V_{KNEE} were reduced and the pulsed drain current was increased. So we think the high temperature thermally treated SiN_X passivation more effectively reduced current collapse than the conventional SiN_X passivation.

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