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Characterization of AlGaN/GaN HFETs on a Si Substrate Grown by MOCVD

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1. Introduction

Although AlGaN/GaN heterojunction field effect transistors (HFETs) have demonstrated remarkable performance on sapphire and SiC [1], the commercial viability of devices grown on these substrates is hampered by cost and high-volume manufacturing issues. On the other hand, the use of mature silicon technology offers a clear commercialization pathway in terms of large-scale wafer fabrication and low-cost manufacturing with relatively good thermal management. Due to these advantages of the use of Si as the substrate, the AlGaN/GaN HFETs on Si have been reported after the demonstration of GaN MESFET on Si [2,3,4]. The low-temperature-grown AlN has been used as a buffer layer for the growth of GaN on Si. However, the crystallinity of the GaN on Si using the low-temperature-grown AlN layer is not sufficient for the device fabrication. Recently, we have reported that the high-temperature-grown AlGaN/GaN intermediate layers contributed to the high quality of GaN on Si [5]. In this study, the characteristics of the AlGaN/GaN HFET on Si substrate using the high-temperature-grown AlGaN/GaN intermediate layers are reported.

2. Experimental

The AlGaN/GaN HFETs were grown on 4-inch Si (111) substrate by metalorganic chemical vapour deposition (MOCVD) system (Taiyo Nippon Sanso: SR-4000). All the layers were grown at 1130˚C. The device structure consists of the 300-nm-thick AlN layers, the 40-nm-thick $Al_{0.26}Ga_{0.74}N$, 20 pairs of GaN/AlN (20/5 nm) multilayers, 1-μm-thick *i*-GaN layer, 1-nm-thick AlN spacer layer, and *i*-$Al_{0.26}Ga_{0.74}N$ (25nm) top layer. The BCl_3 plasma etching was performed for mesa isolation. The source and drain ohmic contacts were formed using Ti/Al/Ni/Au (20/72/12/40 nm) metals followed by lamp annealing at 750 °C for 30 sec. The contact resistance was 1.80 Ω-mm. The gate metal Pd/Ti/Au (40/20/60nm) was formed using conventional photolithography. The schematic structure of the AlGaN/GaN HFETs on 4-inch Si is shown in Fig. 1.

3. Results and discussion

Fig. 2 shows the uniformity of the electrical properties from the Hall effect measurement. The relatively good uniformity was obtained across the 4-inch size wafer. Typical values of the electron mobility, sheet resistance and density of the 2 DEG were 1414 cm^2/Vs, 400 Ω/sq. and $1.1x10^{13}$ cm^{-2}, respectively. A cross-sectional TEM micrograph of the overall structure is shown in Fig. 3. In spite of the smooth interfaces, many dislocations originating from the AlN/Si interface propagate into the upper layer due to the highly mismatched system. The dislocation density was estimated to be $4\text{-}8x10^9$ cm^{-2} for the AlGaN/GaN HFET on Si, which was one order higher than that on sapphire. The full width at half maximum (FWHM) values of X-ray rocking curve (XRC) symmetric (0004) and asymmetric (20-24) reflections were 670 and 1535 arcsec, respectively. The bowing value of the sample was approximately 70 μm. The AlGaN/GaN structure with good crystal quality was obtained on the Si substrate because the Si substrate was protected from meltback etching by the high-temperature-grown AlGaN/AlN intermediate layers. Fig. 4 shows the I_{DS}-V_{DS} characteristics of the AlGaN/GaN HFETs with the gate length of 2 μm and the gate width of 15 μm. The device showed the maximum drain current density (I_{Dmax}) of 632 mA/mm and the maximum extrinsic transconductance (g_{mmax}) of 186 mS/mm.

By use of this heteroepitaxial growth technique, the AlGaN/GaN HFET with a shorter gate length was fabricated on Si in order to study the RF and DC characteristics. Fig. 5 shows the DC characteristics of the device with the gate length of 1.0 μm. The g_{mmax} and I_{Dmax} were as high as 323 mS/mm and 670 mA/mm, respectively. The current gain cutoff frequency (f_T) and a maximum frequency of oscillation (f_{max}) were 26.7 GHz and 57.7 GHz, respectively, as shown in Fig. 6. The device characteristics have been improved by optimising the fabrication process [6].

More recently, the high power AlGaN/GaN HFET has been demonstrated on the conductive Si substrate with the source-via grounding structure [7]. The device with the gate length of 1.0 μm exhibited the g_{mmax} of 200 mS/mm, the I_{Dmax} of 400 mA/mm, the very low specific on-state resistance of 1.9 mΩcm^2, the high off-state breakdown voltage of 350 V, and the current handing capability of 150 A. In addition to these excellent characteristics, the sub-nano second switching t_r of 98 psec and t_f of 96 psec with the current density as high as 2.0 kA/cm^2 were achieved. The excellent characteristics show that the AlGaN/GaN HFET on the conductive Si substrate has a very high quality.

4. Conclusions

The high quality AlGaN/GaN HFET structure has been grown on the 4-inch Si using the high-temperature-grown AlGaN/AlN intermediate layer. The device showed the excellent characteristics for the high frequency and high power applications.

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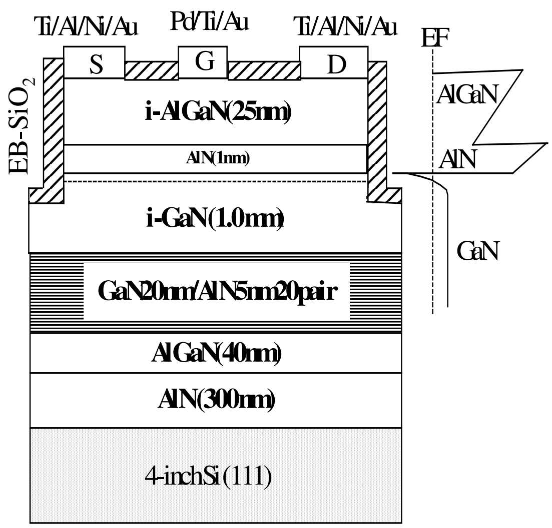

Fig. 1 Schematic structure of the AlGaN/GaN HFETs on 4-inch Si substarte grown by MOCVD.

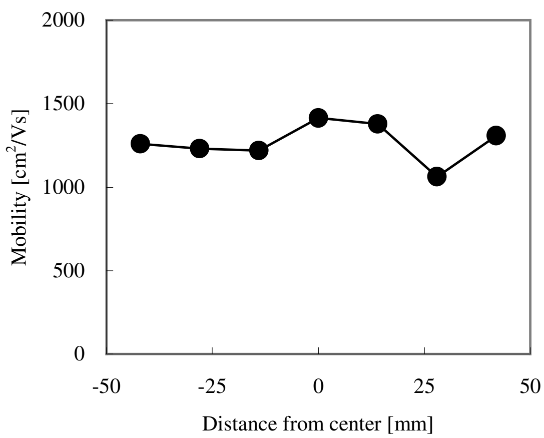

Fig. 2 Uniformity of 2DEG electron mobility for the AlGaN/GaN HFETs on 4-inch Si substarte.

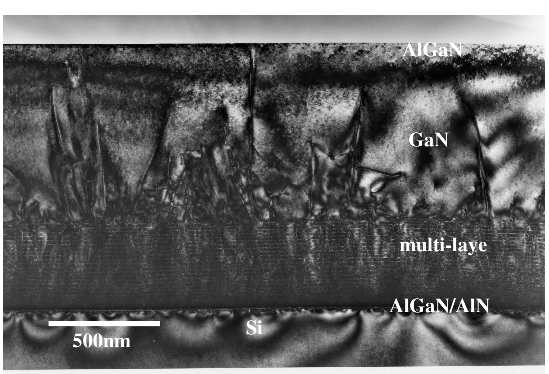

Fig. 3 Cross-sectional TEM micrograph of the overall structure of the AlGaN/GaN HFET on 4-inch Si substrate.

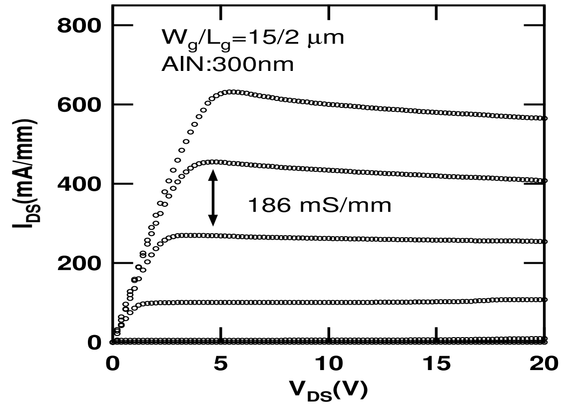

Fig. 4 I_{DS}-V_{DS} characteristics of the AlGaN/GaN HFETs on Si.

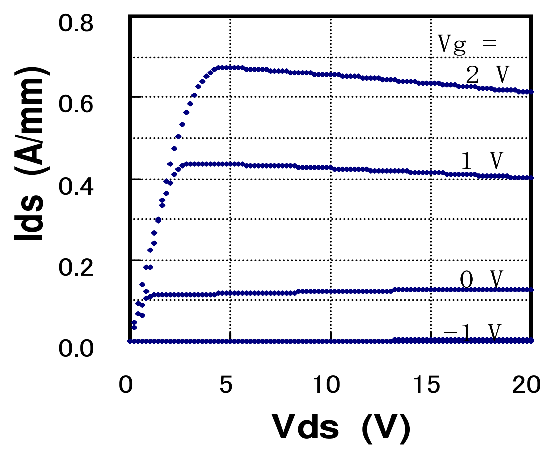

Fig. 5 I_{DS}-V_{DS} characteristic of the device with the gate length of 1.0 µm.

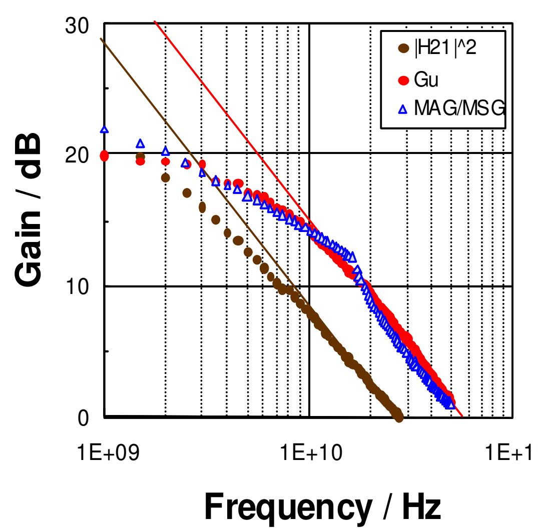

Fig. 6 RF characteristics of the device with the gate length of 0.75 µm.