Relationship between Al content of AlGaN buffer layer on top of initial AlN nucleation layer on Si and vertical leakage current of AlGaN/GaN high-electron-mobility transistor structures

Yuya Yamaoka[1,2], Kazuhiro Ito[2], Akinori Ubukata[1], Yoshiki Yano[1], Toshiya Tabuchi[1], Koh Matsumoto[1], and Takashi Egawa[2]
[1]Taiyo Nippon Sanso Corp.; [2]Nagoya Institute of Technology,
[1]Tsukuba city, Ibaraki 300-2611, Japan; [2]Nagoya city, Aichi 466-8555, Japan
E-mail: Yuya.Yamaoka@tn-sanso.co.jp

***Abstract*—The vertical leakage current of AlGaN/GaN high-electron-mobility transistors on Si substrates was studied. The effects of the Al content in the AlGaN buffer layer and pit density on the vertical leakage current were not as significant as the effect of the initial AlN layer's crystal quality.**

Keywords—AlGaN/GaN HEMT; Si substrate; vertical leakage current

I. INTRODUCTION

AlGaN/GaN high-electron-mobility transistors (HEMTs) on large-diameter Si substrates are promising devices because of their low cost and good thermal conductivity. However, the high vertical leakage current remains an issue. We have been studying the relationship between the crystal quality of the initial AlN nucleation layer on Si and the vertical leakage current of the AlGaN/GaN HEMT fabricated on the Si substrate [1,2]. In this study, we focused on how the Al content in the AlGaN layer on top of the initial AlN nucleation layer (referred to as the AlGaN buffer layer hereafter) is related to the vertical leakage current of the AlGaN/GaN HEMT.

II. EXPERIMENT

All the samples in this study, listed in Table 1, were grown on 8-in p-type Si substrates using a metal–organic chemical vapor deposition (MOCVD) system (UR26K, Taiyo Nippon Sanso Corp.). An AlN layer was grown on each Si substrate to form templates that were similarly affected by the initial AlN layer; Sample E is one of the AlN/Si template substrates that were used in this study. Three types of single AlGaN layers (samples A to C) were grown on identical high-quality AlN/Si template substrates, and three HEMT structures (samples A' to C') were grown on Samples A to C. In addition, a fourth HEMT structure, sample D, was grown on a low-quality AlN layer on the Si substrate without employing the regrowth technique, and there was no passivation layer [1]. Scanning electron microscopy (SEM; S-4700, Hitachi) was used to examine the surface morphology, and X-ray diffractometry (XRD; D8 DISCOVER, Bruker) was employed to determine the crystal quality. Figure 1 shows the structure of the device subjected to current–voltage (*I*–*V*) measurements. The vertical leakage currents were measured using a semiconductor parameter analyzer (B1505A, Agilent Technologies).

III. RESULTS AND DISCUSSION

Figure 2 shows SEM images of the single AlGaN layer samples and the AlN/Si template substrate. By decreasing the Al content of the AlGaN layers, the resulting relative increase in the Ga content effectively decreased the surface pit density. The full width at half maximum (FWHM) of the rocking curve of the each AlGaN layers was almost constant, independent of the Al content. Table 2 shows the FWHM of the rocking curve of the HEMT structures; the corresponding *I*–*V* characteristics of their vertical leakage current are shown in Figure 3. The vertical leakage current increased only when an AlGaN buffer layer with Al content was 0.75. Because FWHM of rocking curve value was almost constant in these three samples, it was supposed that the increase of the vertical leakage current was originated by the increase of the pit density of the AlGaN buffer layer of sample C'. However, this additional increase in the leakage current was relatively small when compared to that due to the effect of the initial AlN layer's low crystal quality in sample D [1].

IV. SUMMARY

The vertical leakage current of the HEMT structures were measured as a function of the Al content in AlGaN buffer layer. The surface pit density of the AlGaN buffer layer decreased as the Al content was decreased, contributing to the reduction in the vertical leakage current of the HEMT structure. Therefore, by improving the crystal quality of the initial AlN layer and reducing the pit density of the AlGaN buffer layer, the HEMT vertical leakage current can be reduced.

[1] Y. Yamaoka, et al.: 11th Topical Workshop on Heterostructure Microelectronics, August 23–26, 2015, Takayama, Japan, pp. 5–6.
[2] Y. Yamaoka, et al.: 2016 MRS Spring Meeting, Phoenix, March 28–April 1, 2016, Arizona, USA, EP6.2.07.

Table 1. Samples used in this study

Sample	Structure	Proportion of Al source in the total metal organic content during AlGaN buffer layer growth	Note
A	Single AlGaN layer	0.25	Growth conditions were the same except for the vapor phase ratio of the Al and Ga sources.
B	Single AlGaN layer	0.50	
C	Single AlGaN layer	0.75	
A′	HEMT structure	0.25	Sample A served as AlGaN buffer layer.
B′	HEMT structure	0.50	Sample B served as AlGaN buffer layer.
C′	HEMT structure	0.75	Sample C served as AlGaN buffer layer.
D [1]	HEMT structure	0.50	This sample did not show regrowth, and there was no passivation layer.
E	AlN/Si template substrate	–	One of the AlN/Si template substrates used in this study

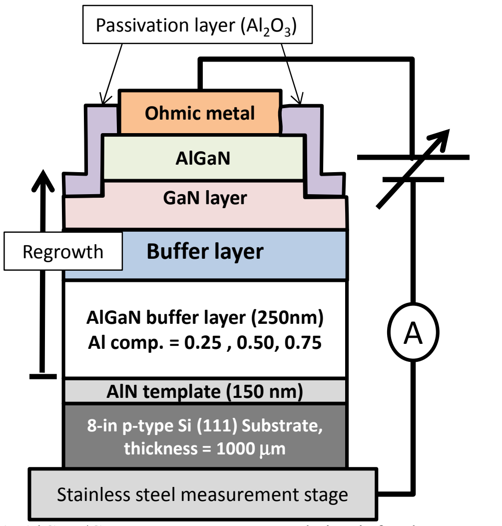

Fig. 1. AlGaN/GaN HEMT structure and circuit for the current-voltage measurement

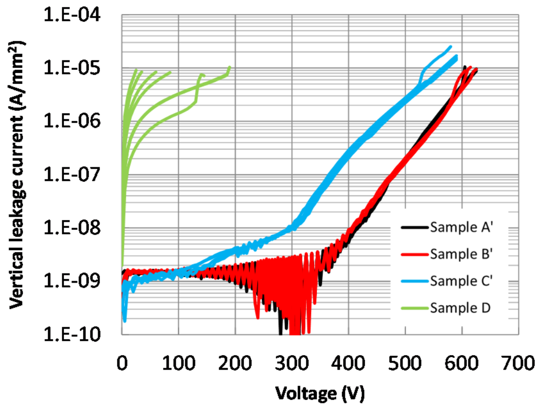

Fig. 3. Characteristics of vertical leakage current

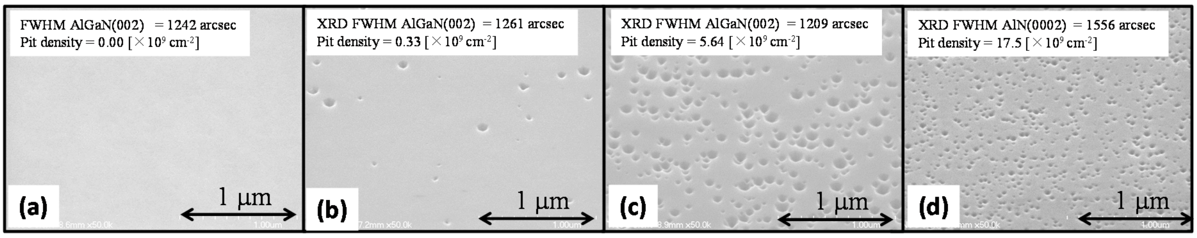

Fig. 2. SEM surface images of the single AlGaN layer and the AlN/Si template substrate: (a) sample A; (b) sample B; (c) sample C; (d) sample E

Table 2. FWHM of rocking curve of each sample

Sample	A′	B′	C′	D [1]
XRD FWHM of AlN(0002) template [arcsec]	1227	1227	1227	2038
XRD FWHM of GaN(002) [arcsec]	584	586	583	691
XRD FWHM of GaN(102) [arcsec]	977	1021	1040	1302