HAL
open science

Towards high buffer breakdown field and high temperature stability AlGaN channel HEMTs on silicon substrate

Jash Mehta, Idriss Abid, Julien Bassaler, Julien Pernot, Philippe Ferrandis, Stephanie Rennesson, T.H. Ngo, Maud Nemoz, Sébastian Tamariz, Yvon Cordier, et al.

To cite this version:

Jash Mehta, Idriss Abid, Julien Bassaler, Julien Pernot, Philippe Ferrandis, et al.. Towards high buffer breakdown field and high temperature stability AlGaN channel HEMTs on silicon substrate. Compound Semiconductor Week, CSW 2022, Jun 2022, Ann Arbor, MI, United States. 2 p. hal-03828829

HAL Id: hal-03828829

https://hal.science/hal-03828829v1

Submitted on 25 Oct 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Towards high buffer breakdown field and high temperature stability AlGaN channel HEMTs on silicon substrate

J. Mehta[1], I. Abid[1], J. Bassaler[2], J. Pernot[2], P. Ferrandis[3], S. Rennesson[4], T. H. Ngo[5], M. Nemoz[5], S. Tamariz[5], Y. Cordier[5], F. Semond[5], and F. Medjdoub[1]

[1]*IEMN, CNRS, University of Lille, 59650 Villeneuve d'Ascq, France*.

[2]*Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France*.

[3]*Université de Toulon, Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble, France*

[4]*EasyGAN SAS, Rue Bernard Grégory, 06905 Sophia Antipolis Cedex, France.*

[5]*CRHEA (CNRS), Rue Bernard Grégory, 06560 Valbonne, France.*

***Abstract*—The rapidly increasing power demand, downsizing of power electronics and material specific performance limitation of silicon has led to the development of AlGaN/GaN heterostructures for high power applications. In this frame, emerging $Al_xGa_{1-x}N$ channel based heterostructures show promising features for next generation of power electronics. In this work, we propose the study of breakdown field variation through the AlGaN channel HEMTs-on-Silicon with various Al composition. The fabricated devices exhibited remarkable buffer breakdown field > 2.5 MV/cm for sub-micron heterostructures grown on silicon substrate. Furthermore, we also experimentally demonstrate that Al-rich AlGaN channel enable both boosting the 3-terminal transistor breakdown voltage and also benefiting from a superior thermal stability.**

Keywords—AlGaN/AlGaN; AlGaN channel HEMT; UWBG

I. INTRODUCTION

In the last decade, wide bandgap (WBG) materials such as GaN and SiC have been a game changer for power electronics compared to conventional Si based devices. To enable multiple kilovolts operation of lateral transistors, ultra-wide bandgap (UWBG) materials (E_G >3.4eV) are attractive. UWBG material $Al_xGa_{1-x}N$ allows control over Al mole fraction providing with a bandgap range up to 6eV along with the spontaneous and piezoelectric polarization, enabling development of heterostructures aiming for high breakdown voltage and low on-state resistance [1]. The major challenge for fabrication of AlGaN HEMT is to optimize source-drain ohmic contacts to achieve high current density especially when using higher Al mole fraction in the channel [2]. In contrast to the best-suited AlN bulk substrate (still too expensive), another challenge is the demonstration of high breakdown field on cost-effective silicon substrate with sufficient material quality. In this study, we experimentally demonstrate superior buffer breakdown electric field and thermal stability of AlGaN channel HEMTs-on-silicon with higher Al content into the channel.

II. EXPERIMENTS AND RESULTS

Submicron AlGaN/AlGaN heterostructures were grown by molecular beam epitaxy (MBE) on low-resistive Si (111) substrate. In the studied structures, $Al_XGa_{1-X}N$ channels are composed of 10%, 30% and 60% Al as shown in sample_A, B and C, respectively (Fig. 1). The devices were mesa isolated (220 nm etching depth) followed by 30nm SiN passivation and Ni/Au metal stack to form 3µm gate length MIS-HEMTs. The output transfer characteristics of fabricated devices show fully functional devices with low off-state leakage and on-state current in agreement with the sheet resistance (degrading with higher Al content as expected). Buffer breakdown electric field as assessed from isolated ohmic contacts through the AlGaN channels increases with the Al-content, from 0.54 MV/cm (sample A) (similar to ultrathin GaN HEMTs on Si) to well-above 2.5 MV/cm (sample C) despite the rather low thickness of the heterostructures grown on silicon substrate (Fig. 2a). It can be noticed that the breakdown electric field becomes independent on the contact distance for the 60% Al-rich channel that prevents the premature electron injection into the silicon substrate owing to its ultra-wide bandgap. As a result, the transistor breakdown voltage (BV) scales well with the Al-content enabling a significant improvement of both BV and off-state leakage current (Fig. 2b and c).

Temperature dependent measurements of DC characteristics reveals that the device with 10% Al showed a severe drop of the on-state current and a complete loss of gate control starting from 350K indicating the activation of defects resulting in high leakage currents (Fig. 3). The drop of maximum drain current density with temperature up to 600K reduces from more than 50% down to 15% while increasing Al composition into the channel from 10% to 60% as shown in Fig. 4a. The off-state leakage variation against temperature shown in Fig.4b confirms the superior thermal stability and temperature operation capabilities of Al-rich AlGaN channel heterostructures on silicon substrate. Thicker buffer and optimized ohmic contacts to Al-rich $Al_xGa_{1-x}N$ channel may enable multiple kilovolts highly scaled transistors.

III. ACKNOWLEDGEMENT

This work was supported by the French RENATECH network, the French National grant ANR-11-LABX-0014 called GaNeXT.

1. J.Y. Tsao et al., Adv. Electron. Mater. **4**, (2018).,
2. A.G. Baca et al., J. Vac. Sci. Technol. A **38**, 020803 (2020)
3. T. Nanjo et al., Appl. Phys. Express **1**, (2008).,
4. I. Abid et al., MDPI Electronics **10**, 635 (2021).

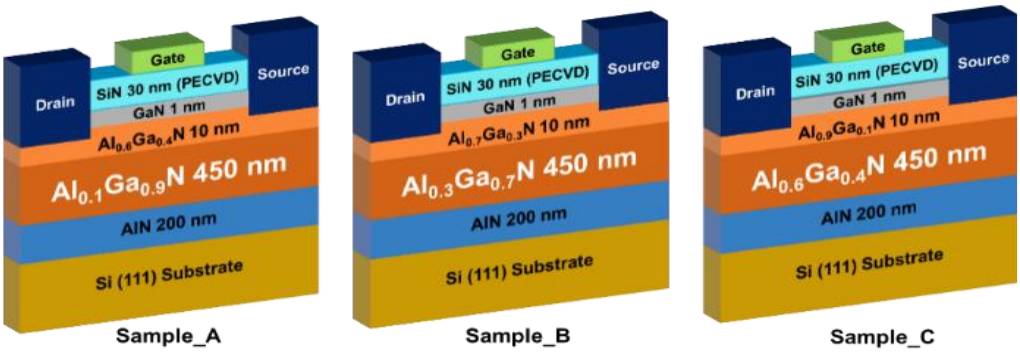

Fig. 1. Cross sectional schematic diagram of AlGaN channel HEMT with different Al composition

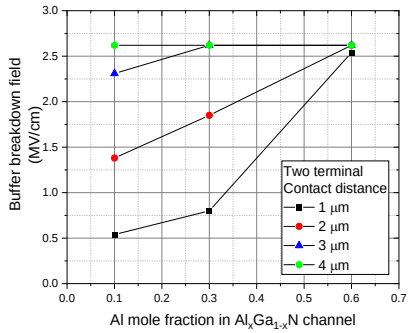

Fig. 2 (a.) buffer breakdown electric field vs. Al mole fraction in AlGaN channel

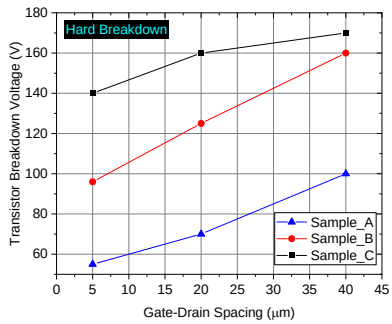

Fig. 2 (b.) Transistor breakdown voltage for various gate-drain spacing

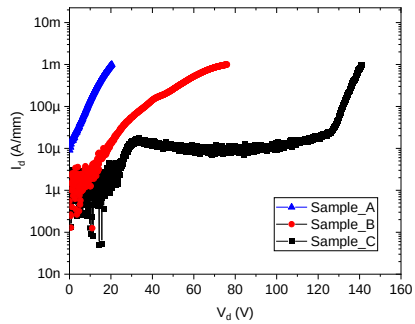

Fig. 2 (c.) Transistor breakdown voltage for a gate-drain spacing of 5µm

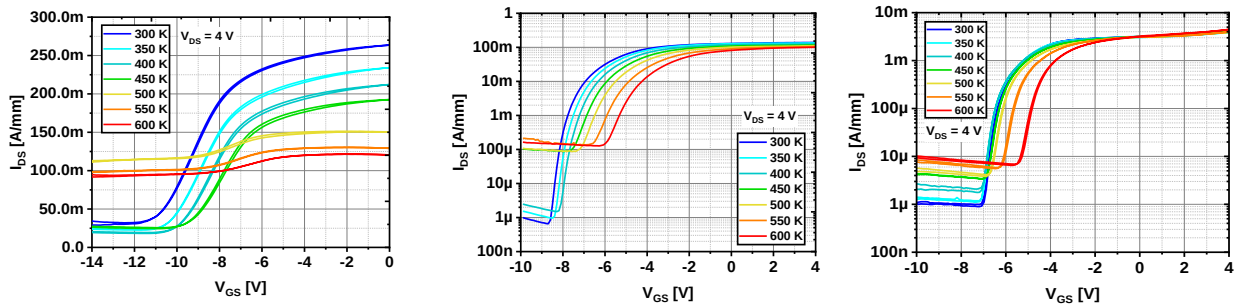

Fig. 3 Id-Vg Temperature measurements of AlGaN channel HEMT with 10% (left), 30% (middle) and 60% (right)

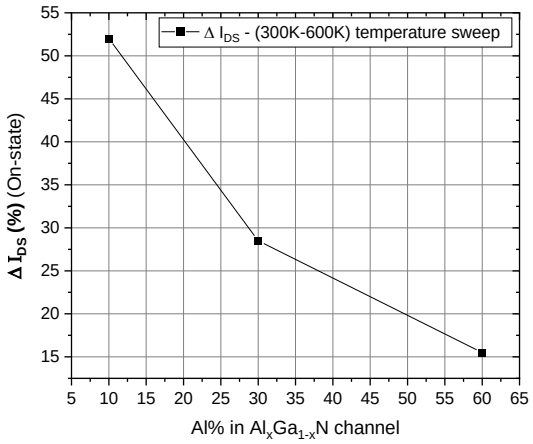

Fig. 4 (a.) Variation in maximum drain current with different Al% content in the AlGaN channel

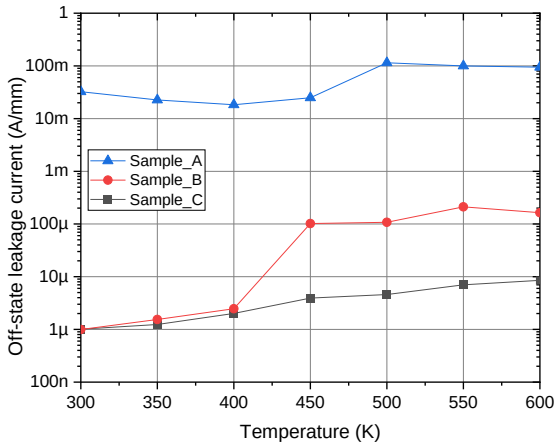

Fig. 4 (b.) Evolution of off-state leakage current with temperature