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# Towards high buffer breakdown field and high temperature stability AlGa<sub>x</sub>N channel HEMTs on silicon substrate

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**Abstract**—The rapidly increasing power demand, downsizing of power electronics and material specific performance limitation of silicon has led to the development of AlGa<sub>x</sub>N/GaN heterostructures for high power applications. In this frame, emerging Al<sub>x</sub>Ga<sub>1-x</sub>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 AlGa<sub>x</sub>N 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 AlGa<sub>x</sub>N channel enable both boosting the 3-terminal transistor breakdown voltage and also benefiting from a superior thermal stability.

**Keywords**—AlGa<sub>x</sub>N/AlGa<sub>x</sub>N; AlGa<sub>x</sub>N 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 ( $E_G > 3.4\text{eV}$ ) are attractive. UWBG material Al<sub>x</sub>Ga<sub>1-x</sub>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 AlGa<sub>x</sub>N 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 AlGa<sub>x</sub>N channel HEMTs-on-silicon with higher Al content into the channel.

## II. EXPERIMENTS AND RESULTS

Submicron AlGa<sub>x</sub>N/AlGa<sub>x</sub>N heterostructures were grown by molecular beam epitaxy (MBE) on low-resistive Si (111) substrate. In the studied structures, Al<sub>x</sub>Ga<sub>1-x</sub>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 AlGa<sub>x</sub>N 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 AlGa<sub>x</sub>N channel heterostructures on silicon substrate. Thicker buffer and optimized ohmic contacts to Al-rich Al<sub>x</sub>Ga<sub>1-x</sub>N channel may enable multiple kilovolts highly scaled transistors.

## III. ACKNOWLEDGEMENT

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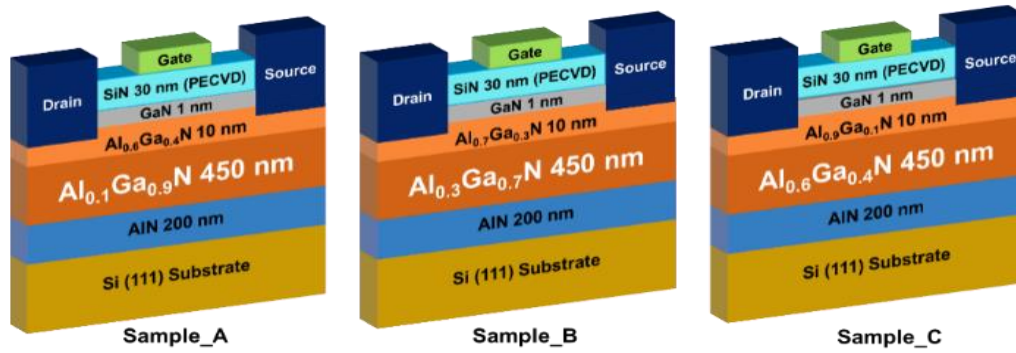


Fig. 1. Cross sectional schematic diagram of AlGaIn channel HEMT with different Al composition

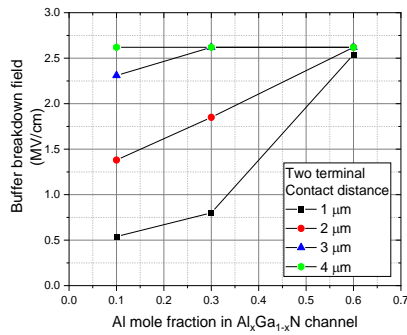


Fig. 2 (a). buffer breakdown electric field vs. Al mole fraction in AlGaIn channel

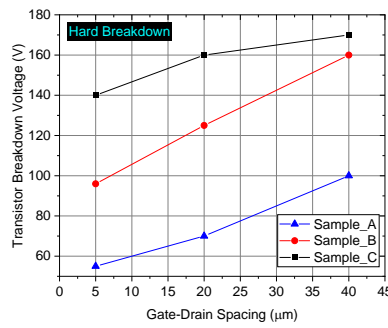


Fig. 2 (b). Transistor breakdown voltage for various gate-drain spacing

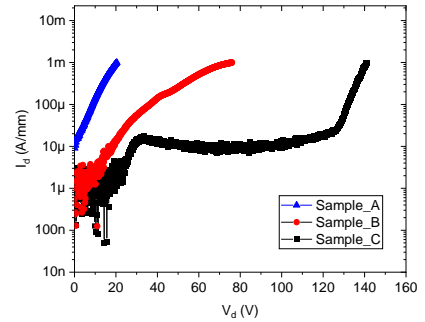


Fig. 2 (c). Transistor breakdown voltage for a gate-drain spacing of 5 μm

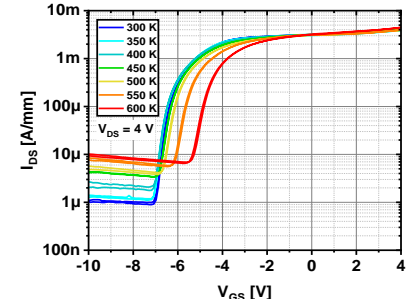
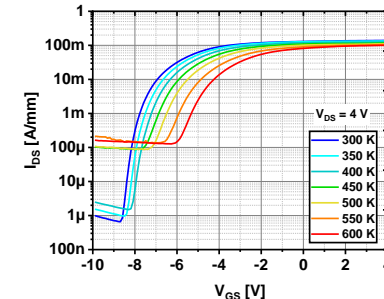
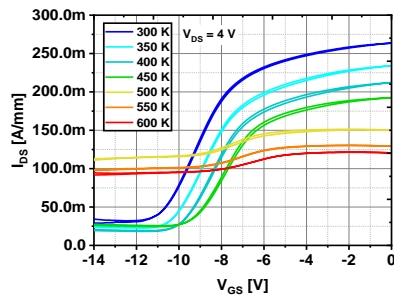


Fig. 3 Id-Vg Temperature measurements of AlGaIn channel HEMT with 10% (left), 30% (middle) and 60% (right)

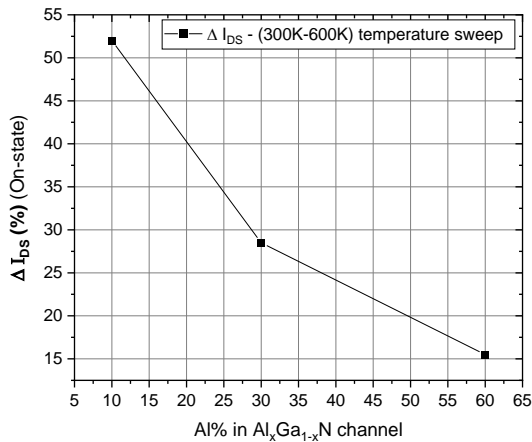


Fig. 4 (a). Variation in maximum drain current with different Al% content in the AlGaIn channel

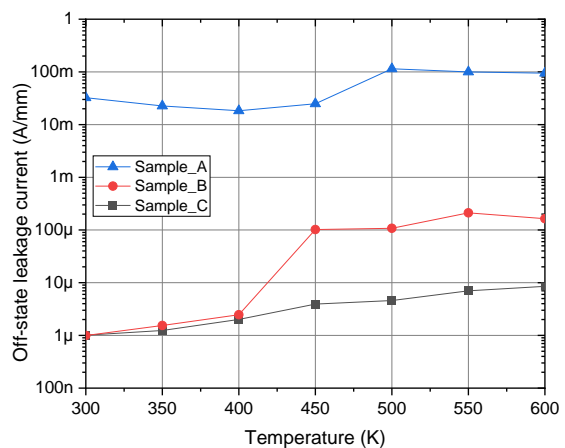


Fig. 4 (b). Evolution of off-state leakage current with temperature