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Polarization-Engineered Ga-Face GaN-Based Heterostructures for Normally-Off Heterostructure Field-Effect Transistors

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Polarization-engineered Ga-face GaN-based heterostructures with a GaN cap layer and an AlGaN/*p*-GaN back barrier have been designed for normally-off field-effect transistors (FETs). The simulation results show that an unintentionally doped GaN cap and *p*-GaN layer in the buffer primarily deplete electrons in the channel and the $Al_{0.2}Ga_{0.8}N$ back barrier helps to pinch off the channel. Experimentally, we have demonstrated a normally-off GaN-based field-effect transistor on the designed GaN cap/$Al_{0.3}Ga_{0.7}N$/GaN channel/$Al_{0.2}Ga_{0.8}N$/*p*-GaN/GaN heterostructure. A positive threshold voltage of 0.2 V and maximum transconductance of 2.6 mS/mm were achieved for 80-μm-long gate devices. The device fabrication process does not require a dry etching process for gate recessing, while highly selective etching of the GaN cap against a very thin $Al_{0.3}GaN_{0.7}N$ top barrier has to be performed to create a two-dimensional electron gas for both the ohmic and access regions. A self-aligned, selective etch of the GaN cap in the access region is introduced, using the gate metal as an etch mask. The absence of gate recess etching is promising for uniform and repeatable threshold voltage control in normally-off AlGaN/GaN heterostructure FETs for power switching applications.

Key words: Normally-off III-nitride heterostructures, polarization engineering, selective etching, GaN cap, AlGaN/*p*-GaN back barrier

INTRODUCTION

GaN-based heterostructures have been considered as promising materials for high-power switching applications as well as high-power microwave applications. This is because the high breakdown voltage and high speed characteristics of GaN-based heterostructure field-effect transistors (HFETs) allow reduction of the on-state loss and switching loss in power electronic applications. In particular, normally-off GaN-based HFETs are desirable for circuit simplification, low power consumption, and failsafe operation in power electronics, as well as diversity in digital circuit applications, while conventional GaN-based HFETs are normally-on. In general, it is difficult to realize normally-off GaN-based heterostructures due to the strong polarization effect. Therefore, efforts on novel heterostructures and gate recess processes have been extensively investigated for realization of a normally-off channel in III-nitride heterostructures. So far, several methods have been reported to achieve enhancement-mode GaN-based HFETs such as gate recess for AlGaN barrier thinning,[1–3] F-based plasma surface treatment,[4,5] utilization of nonpolar heterostructures with a gate-recess process or ohmic regrowth,[6,7] and introduction of a *p*-GaN cap layer or InGaN cap layer in GaN-based heterostructures with ohmic recess.[8–10] These approaches require a plasma-associated process over the semiconductor surface for the gate or as-grown normally-off heterostructures. In general, plasma-free processing would be preferred for normally-off channel

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