Accepted Manuscript

Effect of Two-dimensional Electron Gas on Horizontal Heat Transfer in AlGaN/AlN/GaN Heterojunction Transistors

Xiang Zheng, Shiwei Feng, Yamin Zhang, Yunpeng Jia

PII: S0038-1101(18)30161-8
DOI: https://doi.org/10.1016/j.sse.2018.05.009
Reference: SSE 7436

To appear in: *Solid-State Electronics*

Received Date: 16 March 2018
Revised Date: 13 May 2018
Accepted Date: 24 May 2018

Please cite this article as: Zheng, X., Feng, S., Zhang, Y., Jia, Y., Effect of Two-dimensional Electron Gas on Horizontal Heat Transfer in AlGaN/AlN/GaN Heterojunction Transistors, *Solid-State Electronics* (2018), doi: https://doi.org/10.1016/j.sse.2018.05.009

Effect of Two-dimensional Electron Gas on Horizontal Heat Transfer in AlGaN/AlN/GaN Heterojunction Transistors

Xiang Zheng, Shiwei Feng, Yamin Zhang, and Yunpeng Jia

Abstract—**We propose a specialized gate-drain separation structure for use in investigation of the dynamic behavior of the thermal transport characteristics in AlGaN/AlN/GaN heterojunction transistors. Using this structure, the influence of the two-dimensional electron gas (2DEG) on the horizontal heat transfer in these transistors was identified experimentally. A temperature delay (i.e., the difference in temperature at the same time) of 1.3℃, which accounts for 8.6% of the total temperature rise, was calculated to be caused by a 0.3 μm × 150 μm 2DEG depleted region. In addition, the temperature transients show that the 2DEG can accelerate the temperature to the steady state. Infrared measurements were also carried out to benchmark the results. In particular, the sample structure allows the measurement of a complete thermal process that includes both heating and cooling without interruption. Based on a comparison of the two processes, we demonstrated and corrected an error in the temperature rise that occurred when the Schottky junction voltage was used as the temperature-sensitive parameter.**

Index Terms—**forward Schottky junction voltage, GaN, heat transfer, two-dimensional electron gas (2DEG)**

I. Introduction

Gallium nitride (GaN)-based transistors, such as high-electron-mobility transistors (HEMTs), are highly desirable for use in power applications [1]. However, the application of high voltages and high currents to these devices can cause enhanced heat generation, known as the self-heating effect [2], which leads to a significant increase in temperature in the active region within a microsecond [3]. This repeated rapid lattice-temperature variation over a very short period of time affects the scattering probabilities of the electron, which in turn causes the change of the lattice temperature distribution and thus the uncertainty in device parameters [4]. So, it is essential to study the effect of carriers on the thermal transient for evaluating the micro-wave performance of GaN-based devices using physical measurements performed during operation.

The temperature dependence of the gate Schottky diode characteristics was proposed as a means to investigate the self-heating effect in GaN-based devices [5] because it can measure the temperature of a fully packaged device and acquire the temperature distribution of vertical multilayer materials [6]. However, the conventional device structure limits its ability to study the behavior of the horizontal thermal transfer in the chip level, which contains the influence of carriers on the temperature transient and the device characteristics.

The authors are with the Institute of Semiconductor Device Reliability Physics, Beijing University of Technology, Beijing, 100124, China (e-mail: shwfeng@bjut.edu.cn and yaminzhang@bjut.edu.cn).

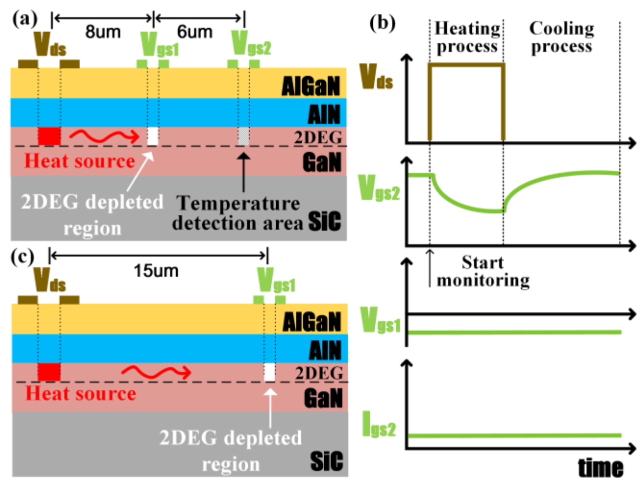

FIG. 1. (a) Structure of the specialized sample A. A 0.3 μm×150 μm 2DEG control area using a Schottky diode is located in the heat transfer path along the channel. (b) Biasing sequence for measurement of the variation of the forward Schottky voltage (V_{gs2}) at a constant current (I_{gs2}). A complete measurement cycle contains two processes of both heating and cooling. (c) Structure of the sample B with a longer distance between the heat source and the Schottky diode used in the infrared measurements.

In this paper, we proposed a specialized gate-drain separation structure to investigate the dynamic behavior of the thermal transport characteristics in AlGaN/AlN/GaN heterojunction samples. Using this structure, we demonstrated the effect of the two-dimensional electron gas (2DEG) in the horizontal heat transfer process. A delay of the temperature variation caused by the depletion of the 2DEG on the lateral heat transfer path was observed. Additionally, we investigated the effect of traps on the calculation of temperature rise and corrected the value for the first time when the forward Schottky junction voltage is used as the temperature sensitive parameter.

II. Sample Structure

The samples that were used in this work were designed as shown in Fig. 1(a) and (c), which procured from the 55th Research Institute of China Electronics Technology Group Corporation. These AlGaN/AlN/GaN samples were grown on SiC substrates by metal-organic chemical vapor deposition. The GaN and $Al_{0.25}GaN_{0.75}$ layer thicknesses were 1.5 μm and 25 nm, respectively. A 1-nm-thick AlN insert layer was located between the GaN layer and the AlGaN layer. The SiC substrates were 80 μm thick. These samples were passivated using a 100-nm-thick Si_3N_4 layer. Sample A had three specific regions, including a heat source area, a 2DEG control area, and a temperature detection area while sample B had a longer distance between the heat source and the 2DEG control area.