Solid-State Electronics 62 (2011) 5–13

Contents lists available at ScienceDirect

Solid-State Electronics

journal homepage: www.elsevier.com/locate/sse

Atomistic and electrical simulations of a GaN–AlN–(4H)SiC heterostructure optically-triggered vertical power semiconductor device

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A R T I C L E   I N F O

Article history:
Received 20 July 2010
Accepted 16 March 2011
Available online 4 May 2011

The review of this paper was arranged by Prof. S. Cristoloveanu

Keywords:
Vertical power semiconductor device
GaN
4H–SiC
AlN
Optical triggering
Simulation

A B S T R A C T

In this paper, a comprehensive simulation study is conducted to investigate the switching characteristics, gain, and breakdown voltage of a GaN–AlN–(4H)SiC based optically-triggered (OT) heterostructure *vertical* power semiconductor device (PSD). It comprises a 1 nm AlN buffer layer between the GaN and SiC heterointerface to achieve a reasonable compromise between lattice mismatch and lower forward drop. The results are compared with an all-(4H)SiC OT PSD. The all-(4H)SiC homostructure PSD is based completely on SiC and has no buffer layer. Further, it has the same structure, dimensions, and doping densities as that of the GaN–AlN–(4H)SiC based heterostructure PSD. While there have been studies on GaN–AlN–SiC lateral heterostructures, their primary focus has been on lateral conduction in the GaN structure with a thick (typically >300 nm) AlN buffer layer residing on top of a SiC substrate. Such an approach will not be useful for our vertical PSD because of the thick AlN layer. As such, first, a scaled molecular dynamics simulation (MDS) is carried out in $DMol^3$ emulating the GaN–AlN–(4H)SiC heterointerface pn junction of the vertical PSD (with 1 nm AlN buffer) to assess the possibility of vertical conduction and stability of the heterointerface by calculating the density of states (DOS) at the Fermi level and the potential energy, respectively. Subsequently, detailed electrical simulations of the GaN–AlN–(4H)SiC and all-(4H)SiC vertical PSDs are carried out in Silvaco to assess their switching performances, gain, on-state drop, and blocking capabilities. The overall results indicate that, the GaN–AlN–(4H)SiC vertical PSD provides superior switching performance and optical absorption compared to the all-(4H)SiC vertical PSD, while the latter provides better gain. The blocking capabilities and forward drops are found to be comparable for both the PSDs from a practical standpoint.

1. Introduction

Optically-triggered (OT) power semiconductor devices (PSDs) have great potential for high-voltage (HV) and high-power-electronics application. By optically controlling the PSD of a HV power stage, complete electrical isolation between the low-voltage controller and HV power stages can be ensured. Further, electromagnetic-interference (EMI) immunity of the control link between the controller and power stage is realized as well. The earlier work on OT PSD has focused primarily on Si- and GaAs-based devices. The choice of direct bandgap GaAs has been motivated by its high optical absorption coefficient (OAC), while the choice of indirect bandgap Si has been primarily motivated by cost reduction. However, these GaAs- and Si-based OT PSDs have breakdown voltage and current–density limitations due to the low bandgap and thermal conductivity of these materials. The semiconductor materials, GaN and SiC, have great potentials for high-temperature and high-power-electronics application because of their attractive material properties such as large bandgap energies, high breakdown fields and high thermal conductivities [1–3]. The material GaN has very good optical absorption coefficient and short carrier lifetime [1–3]. Recently a SiC based OT thyristor has been proposed. The choice of thyristor as the PSD structure is motivated by the high electrical gain of the PSD that somewhat compensates for the low OAC of SiC thereby precluding the need for a high-power short-wavelength laser, which is a difficult proposition from cost and availability standpoints. Unfortunately, the inefficient turn-off characteristics of the SiC thyristor due to its internal latching action limits the operation of the PSD for high-frequency power-electronics application and, instead, more suited for pulsed-power application.

One way of addressing the limitations of SiC is to synthesize an OT PSD based on GaN, which has higher OAC compared to SiC. Currently, however, this technological possibility is limited by size and quality of GaN substrates even though progress is being made. An

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0038-1101/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2011.03.008

alternate option, which is pursued in this paper, is to synthesize a GaN–(4H)SiC heterostructure OT PSD with GaN addressing the optical-triggering aspect of the device due to its higher OAC while SiC addressing the high-temperature sustenance of the device. The

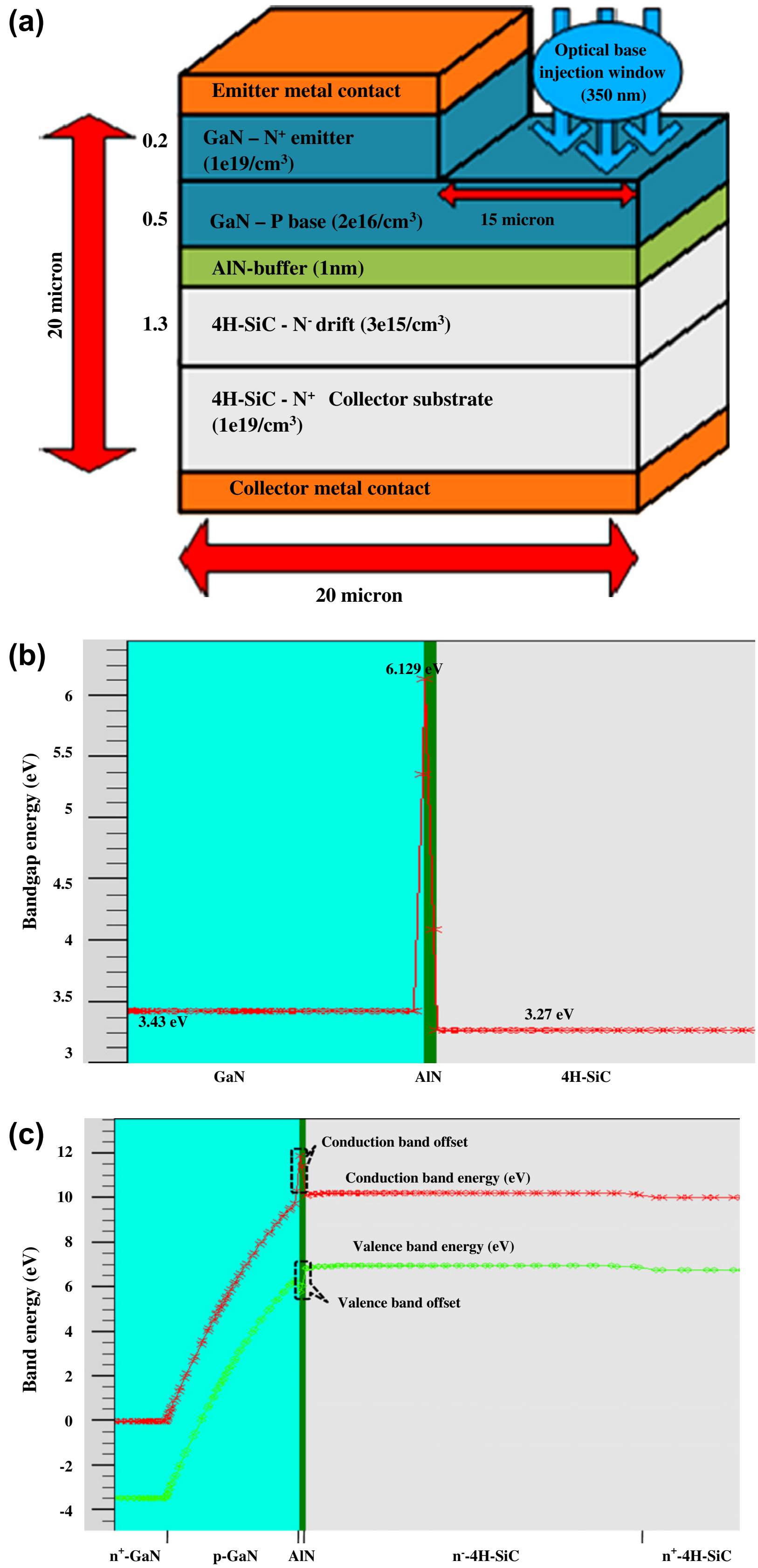

Fig. 1. (a) GaN–AlN–(4H)SiC based OT heterostructure PSD. (b) Bandgap profile of GaN–AlN–(4H)SiC heteromaterial system. (c) Conduction- and valence-band energies corresponding to the device structure shown in (a).