43rd Workshop on Compound Semiconductor Devices and Integrated Circuits Report

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Introduction

The 43rd Workshop on Compound Semiconductor Devices and Integrated Circuits (WOCSDICE) was held on Cabourg France from 17-19 June 2019. This conference focused on the state-of-the-art research and latest advancements on devices-based compound materials, and it was chaired by Farid Medjdoub from CNRS-IEMN, France. There were 51 presentations in total which were divided into 10 sessions: GaN power devices, RF GaN devices, Novel device and circuit concepts, Optoelectronic devices and modelling, 2D materials and devices, Thermal and reliability aspects, Device processing, Ultra-wide bandgaps, Novel device and circuit concepts II, Advanced characterization. Some of the talks I found very interesting are explained below.

Selected Presentations

Recent Progress of Vertical GaN power devices on GaN substrates (T. Oka, Toyoda Gosei, Japan)

The speaker introduced a new design for GaN MOSFET – Vertical GaN Trench MOSFET. This structure consists of a n-type GaN layer on the bottom (Drain) and a p-type GaN layer on the top (Source) to conduct the current vertically. A trench is etched on the middle of the top p-type layer and is covered with a SiO_2 layer to form a Schottky gate.

To improve the current density of this device, a well-designed current distribution layer (CDL) was made within the stack. It is basically made by a heavily n-doped GaN layer which will modify the current flow distribution.

According to the measurement results, this new type of device shows a high breakdown voltage (~ 1250 V), low ON-resistance (~ 1.8 mΩcm^2) and high frequency operation (> 8 MHz), thus reveals a potential of vertical GaN devices for use in high-frequency switching power applications. Normally-off operation with a threshold voltage of 3.5 V was also exhibited. Another main benefit for this device is that it will significantly reduce the chip size and cost compared to the lateral GaN transistor which requires a larger wafer size.

However, compared to the GaN HEMTs, this device shows a relatively lower electron mobility due to the lack of 2DEG. As a result, although its maximum operation power is higher than the GaN HEMTs, its maximum operation frequency should be lower. Hence, the author is still working to improve its performance and to pursue a suitable application situation.

Review of vertical GaN-based FETs (E. Bahat Treidel, FBH Berlin, Germany)

In this presentation, the speaker showed the state-to-the-art research progress of the vertical GaN-based FETs. Due to the availability of relatively high quality free-standing bulk GaN substrates, research and developments of vertical GaN devices on GaN substrates are getting hot in recent years, and various transistors and diodes based on vertical GaN with excellent characteristics have been reported. The major advantage for the GaN-on-GaN homo-epitaxy is that there is no lattice mismatch between the substrate and the epi-layer. Consequently, it is much easier to achieve smaller bow and strain within the structure. However, GaN substrate has a much worse thermal conductivity than Si, SiC and sapphire and is much more expensive.

The speaker summarized the pros and cons for the lateral and vertical GaN devices. For the lateral devices, the 2DEG is normally present in the GaN HEMTs resulting in a high electron mobility. However, the large wafer size, normally-ON nature and non uniform heat generation limit the performance of the lateral devices. In the vertical devices, a higher current density is able to achieve in a small wafer size due to the vertical conduction and normally-OFF devices are easier to be fabricated (MISFETs). The existing problems for the vertical GaN devices are inter-device insulation (edge termination), vertical leakage and parasitic npn BJT (poor body diode).

The speaker also introduced some well-designed vertical GaN devices listed below:

1. CAVET: current aperture vertical electron transistor (UCSB, Toyota, Avogy/Nexgen)
2. Vertical heterojunction FET (Sumitomo, Panasonic)
3. Trench n-channel MISFET/MOSFET (Toyota, Toyoda Gosei, UCSB, HRL, FBH)
4. Vertical FinFET (MIT)
5. OG-MOSFET (UCSB)
6. Quasi-vertical (Panasonic, FBH)

GaN-on-Silicon buffer decomposition experiment: analysis of the vertical leakage current (M. Borga, University of Padova, Italy)

The aim of this work is to analyse the mechanisms for the off-state vertical leakage current layer by layer, which normally contribute to the losses of devices during operation. In the presentation, the speaker showed three different samples for vertical leakage current measurements.

The first sample consists of a p-doped Si substrate, a 200-nm AlN layer (strain relief layer) and an Ohmic contact on the top. In the second sample, there is an additional 350-nm AlGaN layer deposited between the AlN layer and the Ohmic contact. In the third sample, a 2450-nm C-doped GaN layer was deposited between the AlGaN layer and the Ohmic contact.

The temperature-dependent I-V measurements were conducted on the three samples. In the first sample, there is no temperature dependent behaviour of the vertical leakage current demonstrating that the total current is mainly limited by the carrier injection from the Si substrate to the AlN layer (tunnelling effect). However, the dependence of leakage current with temperature is found in the second and third sample. Moreover, in the third sample the vertical leakage current becomes much higher compared to the other samples, especially at the high temperature. The speaker argued that in the second sample the leakage current was dominated by the trap-assisted conduction within the AlGaN layer which was temperature-dependent process. And in the third sample, there were some additional holes originated from the C-doped layer flowing to the substrate (small hole barrier in the valance band) which finally contributed to the increase the vertical leakage current.

However, in the Q&A part, some researchers also pointed out the Ohmic contacts might not be reliable in different samples and would also affect the vertical current.

GaN Schottky diodes for proton beam monitoring (Jean-Yves Duboz, Universite Cote d'Azur, France)

In this work, the speaker aimed to use the GaN Schottky diodes for proton beam monitoring. Firstly, the speaker compared the GaN Schottky diodes and Si Schottky diodes. The Si Schottky diodes appeared to be vulnerable to the proton beam while the GaN Schottky diodes showed a much larger lifetime in the proton beam monitoring. This is due to that the energy of the atomic bonds in Si is much smaller than that in GaN. As a result, the atomic bonds in Si can be easily destroyed by the proton and the whole structure would be distorted.

In this technique, the GaN Schottky diode was illuminated with the proton beam and the current was measured at different fixed bias points. According to the measurement results, this technique shows a good linearity of the diode current with the proton beam intensity at both forward and reverse biases. Consequently, the proton beam intensity could be measured precisely by the diode current. Furthermore, the transient measurements have also been conducted and a fast response time (< 1 s) was reported by the speaker.

In conclusion, these promising results indicate the possible application of the GaN Schottky diodes for proton beam monitoring, especially for the proton therapy.

Dependence of Breakdown Voltage on Gate-to-Drain Distance AlGaN/GaN HEMTs with High-k Passivation Layer (K. Horio, Shibaura Inst., Japan)

This work is mainly simulation-based analysis for the breakdown voltage analysis in AlGaN/GaN HEMTs. The presenter firstly proposed three common ways to enhance the breakdown voltage – using field plates, increasing the Gate-to-Drain distance and increasing the acceptor density in the buffer (Fe-doped). Comprehensive 2D-TCAD simulations were performed by calculating the Poisson equation and the current continuity equation to investigate how different parameters affect the breakdown voltage.

The simulation finally pointed out the breakdown voltage could be significantly improved by increasing the permittivity of passivation layer, which might offer a new direction for the device design.

AlGaN/GaN High Electron Mobility Transistors with thin channel on Ultra Wide Bandgap AlN buffer (I. Abidm, CNRS-IEMN, France)

In this study, the presenter measured two samples of AlGaN/GaN HEMTs with different structures and determined that a higher breakdown voltage could be achieved by a thin GaN channel combined with a thick AlN buffer.

The first sample has an 8-nm GaN channel with a 190-nm AlN buffer layer, and the second one has a 240-nm GaN channel with a 75-nm AlN buffer layer. The measured breakdown voltage for the first sample is about 1000 V while that for the second sample is only around 270 V. The electrical field was also measured in the TLM structures. The breakdown field for the first sample is ~ 5 MV/cm and in the second sample it is reduced to ~1.35 MV/cm. Based on these results, the presenter argued that AlN, which had a larger bandgap than GaN, could withstand a higher electrical field and thus increased the breakdown voltage.

Defect Analysis of InAlGaN/GaN/SiC HEMT heterostructures (L. Stuchlikova, Slovak University of Technology, Slovakia)

In this work, the speaker used deep level transient Fourier spectroscopy (DLTFS) to characterize the defects in the InAlGaN/GaN HEMT heterostructures grown on N-doped SiC substrate with semi-insulating epitaxial nature SiC layer and with AlGaN back barrier between and an AlN nucleation layer and a GaN buffer.

InAlGaN/GaN technology has proven interesting power performances for Ka Band applications and is possible to reach even higher frequencies (E Band) to address emerging 5G standards. In the testing structure, there is an AlGaN back barrier inserted between the AlN nucleation layer and the GaN buffer which will help to reduce the leakage current, increase I_{ON}/I_{OFF} ratio, avoid the formation of islands and undulations during growth process, and modify the stress induced in the structure and the final wafer bow.

The activation energies, carrier capture cross sections and densities of these traps can be characterized by the static CV measurements (1 MHz) at different temperatures ranging from 80 to 550 K. With DLTFS, 3 electron type defects with activation energies of 0.14, 0.16, 0.17 eV and 2 hole type defects with activation energies of 0.47, 0.52 eV are found in the testing device. The speaker treated the activation energies and the carrier capture cross sections as the finger prints for the defects. By comparing the measurement results and the reported literature, the speaker successfully associated the electron traps with the carbon and hydrogen impurities in the structure and the hole traps with the nitrogen vacancies.

Concluding Remarks

I really appreciate the UKNC for providing me with the bursary which helped me to attend WOCSDICE 2019. In this conference, I got the opportunity to present my work on hard-switching study and listen to different views towards it. More importantly, I was able to hear the state-to-the-art research progress among the Gallium Nitride communities. I gained lots of experience and the knowledge from the discussion with the attenders which will greatly help my future study.