Grenze International Journal of Engineering and Technology, Jan Issue

Creation of a Vertical Gallium Arsenide (GaAs) Channel High Electron Mobility Transistor (HEMT) for Power Applications in Integrated Circuit (IC) Technology

Geethanjali G.C[1], Dr. Pavithra G[2] and Dr. T.C.Manjunath[3]
[1]First Year (Second Sem), USN: 1DS22LVS03, M.Tech. (ECE) Student,
VLSI Design & Embedded Systems Specialization, Dept. of Electronics & Communication Engineering,
Dayananda Sagar College of Engineering, Bangalore
[2]Associate Professor & Guide, Dept. of Electronics & Communication Engg., Dayananda Sagar College of Engineering,
Bangalore, Karnataka
[3]Professor & Head, Co-Guide, Dept. of Electronics & Communication Engg., Dayananda Sagar College of Engineering,
Bangalore, Karnataka

***Abstract*— The research article investigates the development of Vertical Gallium Arsenide (GaAs) Channel High Electron Mobility Transistor (HEMT) for Power Applications in IC Technology. This specialized transistor, the Vertical GaAs Channel HEMT, is designed with unique properties enabling its application in high-frequency and high-power operations, particularly in power-related contexts. The abstract succinctly encapsulates the ongoing progress in this development, emphasizing its primary focus on enhancing power efficiency and performance within integrated circuits (ICs). The innovation seeks to facilitate the creation of more compact and efficient electronic devices by integrating power applications seamlessly into ICs. Notably, the technology's ability to operate at higher frequencies renders it pertinent for applications in communication and radar systems. The study also explores the potential for reducing power consumption, aligning with the industry's overarching commitment to energy-efficient electronics. The broader applications of Vertical GaAs Channel HEMT extend into emerging fields such as 5G communication and satellite technology, signifying substantial advancements in the realm of advanced and efficient electronic systems. The abstract concludes by recommending researchers refer to recent academic journals and industry publications for the latest updates on semiconductor advancements.**

***Index Terms*— Template, Scribbr, Gallium, Arsenide, Simulation, FET, MOSFET, Simulation**

I. INTRODUCTION

The High Electrons Mobility Transistors (HEMT), alternatively recognized as a hetero-structure FET [HFET] or a modulation doped FET [MODFET], represents a category of field effect transistors distinguished by the presence of a junction’s formed between 2 material possessing distinct bandgaps. The most prevalent material combination for HEMTs is gallium arsenide (GaAs) with aluminum gallium arsenide (AlGaAs). HEMTs containing more indium typically exhibit superior higher frequency performances. However, in modern year, gallium nitrides

Grenze ID: 01.GIJET.10.1.529_2

HEMT’s has garnered attentions for their exceptional high-power performance. Functioning as digital on-off switches in integrated circuits, HEMTs leverage their unique current–voltage characteristics to serve as the amplifier for large current amount, controlled by a small voltage type signals. HEMT transistors distinguish themselves by operating at higher frequencies, reaching milli-meter type wave frequency. Their application span various higher-frequency product, including cell phone, satellite TV receiver, voltage converter & radar equipments. Particularly prevalent in satellite receiver, lower-power amplifier & the defense industries, HEMTs play a crucial role in advancing electronic capabilities, especially in applications demanding high-frequency performance.

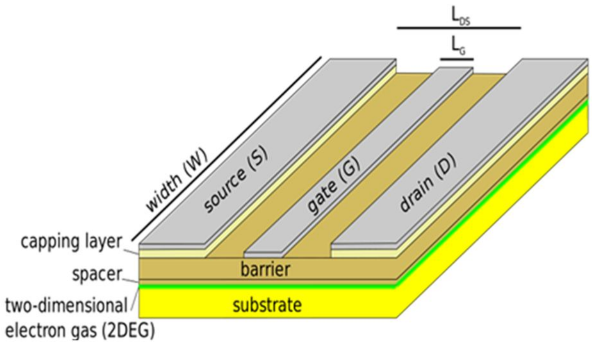

Fig. 1 : DC outputs & the transfer characteristic curve of the vertical GaAs transistors

Then, the Vertical GaAs (gallium arsenide) Channel High Electron Mobility Transistor (HEMT) stands out for its distinctive qualities that render it well-suited for high-frequency and high-power operations, making it a valuable choice for power applications. In parallel, Gallium Nitride (GaN) and its related wide bandgap semiconductor alloys have emerged as leading contenders for the next generations of higher power & higher frequencies electronic device. GaN-based devices exhibit a higher breakdown field and drift velocity compared to silicon (Si) counterparts, resulting in lower losses, particularly at elevated voltage and temperature levels. These superior performances are not solely attributed to the inherent material properties of GaN but are also closely tied to the device technology rooted in AlGaN/GaN heterostructures. The combination of unique material characteristics and advanced device technology positions GaN-based transistors, such as Vertical GaAs Channel HEMTs, as promising candidates for pushing the boundaries of electronic capabilities in power applications, especially where high-frequency and high-power performance are paramount.

II. Literature Survey

In this section, a brief literature review about the works carried out by other authors is presented in a nutshell.

A. Advancements in Gallium Nitride (GaN)-Based Power High Electron Mobility Transistor (HEMT) Devices

This review provides a comprehensive overview of strategies aimed at enhancing the performances of Gallium Nitride (GaNs)-dependent power High Electrons Mobility Transistors [HEMT] device. It delves into modified epitaxial structures designed to mitigate defects and current leakage, offering insights into how these alterations contribute to improved device functionality. Additionally, the review explores recess-free processes that are low in damage, particularly in the context of fabricating normally-off HEMTs. A significant focus is directed towards the potential impact of dielectrics on metal–insulator–semiconductor (MIS) structures, with a thorough examination of their effects on device performance. By addressing these critical aspects, the review provides a valuable resource for understanding and implementing effective approaches to optimize GaN-based power HEMTs, thus advancing the state-of-the-art in power semiconductor technology.

B. Exploration of AlGaN Channel High Electron Mobility Transistors on β-Ga2O3 Substrate for High-Power Electronics

The article focuses on the advantages of wider bandgap AlGaN (with an energy gap, eg., greater than 3.4 electron Volt) channel dependent Higher Electrons Mobility Transistors (HEMTs), particularly in the context of high voltage operation. AlGaN channel HEMTs offer notable benefits such as a higher critical type of electrical fields & higher saturation velocities. These advantages extend the operating regime of power electronics to higher levels. The study specifically presents the direct current [DC] characteristic of Al-GaN channel’s-based HEMT’s with a gate lengths [LG] of 0.8 µ-m and a gate-drain distances (LGD) of 1 µ-m. Importantly, these HEMTs are fabricated on an ultra-wide bandgap β-Ga2O3 substrate, suggesting an exploration of advanced materials for power electronic applications. The research likely contributes insights into the potential and performance of AlGaN channel-based HEMTs, emphasizing their application on substrates with unique properties like ultra-wide bandgap β-Ga2O3.

C. OG-FET: A Vertical Trench MOSFET Utilizing In-Situ Oxide and GaN Interlayers

This research paper introduces a novel design for a distinctive device characterized by lower on the resistances & enhancement type of modal operations within a vertically domain type of Gallium Nitride [GaN] Field-Effect Transistor (FET). The channel is formed at the interface between the dielectric and p-GaN through p-GaN inversion within the conventional trench Metal-Oxide-Semiconductor FET (MOSFET) structure. In this configuration, an dielectrics are deposited on the NPN trenched structures. However, the inherent drawback of relatively high on-resistance due to the low electron mobility in the channel is addressed by modifying the structure. This modification involves the incorporation of an in situ dielectrics cap [MOCVD Al_2O_3] on the NPN trenched structures, followed by the growth of a Metal Organic Chemical type of Vapor Depositions [MOCVD]-regrown UID based GaN interlayers. This alteration effectively establishes a conduit (channel) that enhances electrons mobilities in the channels, thereby achieving a significant reduction in on-resistance. This innovative design demonstrates the potential for improved performance in vertical GaN FETs, marking a notable advancement in the realm of semiconductor device engineering.

D. Power Applications

This study provides a detailed account of the epitaxial synthesis of the vertical drift zone and p-type blocking layers of Gallium Arsenide (GaAs) on 2-inch bulk GaAs substrates, utilizing metal based organic chemical vapored depositions [MOCVD]. Notably, the threading type of dislocation densities in the film growths on these bulks GaAs substrate are remarkably low, measuring 104 cm^{-2}. This figure is at least 4^{th} order of magnitudes lesser than film which are cultivated on Silicon [Si] or Silicon Carbide [SiC] substrate, as evidenced by planar view of the cathode luminescence's [CL] imaging's. The designs of the n-typed drift layers, encompassing thickness and dopings considerations, significantly influences the maximal break-down voltages of the device. In the scrutinized devices, the nominal netted doping densities in the drifted region are given by ND - NA = 1 × 1016 cm^{-3}, and the drifted layer's thickness are = 15 μ-m. The p type regions are formed through the in situ growths of Mg type of doped p+ GaAs epitaxium. This investigation underscores the potential of MOCVD in achieving high-quality epitaxial growth on bulk GaAs substrates, suggesting advancements in the performance of electronic devices..

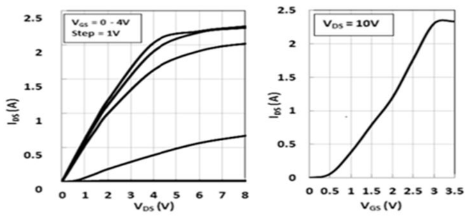

Fig. 2 : V-I Characteristic Curves

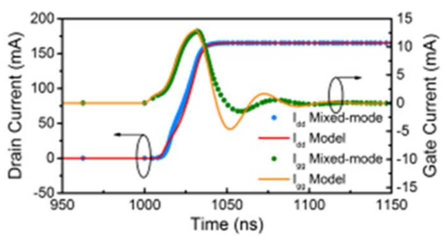

Fig. 3 : Gate current characteristics

In the fabrication process, the trenches were filled, and a channel was established above the pattern type of 'p' type GaAs layers by regrowing an n type GaAs layers. This n-type layers are subsequently capped' with an AlGaAs layer containing 20% aluminum. At the hetero-interface between AlGaAs and GaAs, polarization-induced charge generated a two-dimensional electron gas (2DEG) channel. Following deposition and patterning, the upper gate was formed by creating the ‘p’ type GaA’s layers. The dopings and thickness of the ‘p’ type As layer were carefully considered, strategically influencing the charge at the AlGaN/GaAs interface and within the channel area. This design approach was implemented with a positive threshold energy in mind, contributing to the controlled formation and modulation of charge carriers in the device.

III. RESULTS & DISCUSSIONS

The investigation involves transient simulations that concentrate on switching transients, utilizing a 1.5 Mega Hertz pulses with a pulse width of 490 ns & the fall time and rise time of 20 ns at the extrinsic type of gates. Time domained waveform for the intrinsic gate’s voltage (V_{gi}), drained voltage (V_{di}), & the drained currents (I_d) are captured throughout the turn-off & turn-on phases. At the same times, a model cards for the Technology Computer-Aided Design (TCAD) device is derived from I_d / V_g, I_d / V_d & the CV datas utilizing a previously outlined parametric extraction type of procedures. The identical Spiced net-list is applied for the transient circuit’s simulations in Keysight Advanced Design System [ADS] simulators, maintaining uniform operating condition as with the mixed type of modal netlists.

The results furnish a comparisons of model based TD waveform for intrinsic type of drained voltages, the gate voltages & the drained currents along with the mixed type of modal simulations which take place during the turn off & turn on modes. The impact of the Floating Poly [FP] Models, incorporating cross couplings & the substrate’s capacitance, is emphasized. Model’s prediction exhibit satisfactory accuracy in estimating transient characteristics, including drained overshoot because of the L-C ringings. The accompanying figures depict a comparisons of the modeled TD based waveform during the turn off’s and turn on’s without & with the enhanced [FP] Models, illustrating the effectiveness of the improved models.

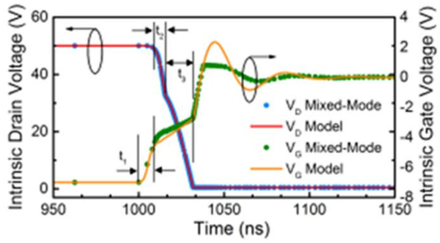

Fig. 5 : Simulation result-1

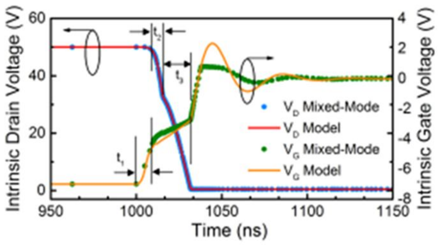

Fig. 5 : Simulation resul-2

IV. NOTE ON THE RESULTS OF VERTICAL GAAS CHANNEL HEMT DEVELOPMENT FOR POWER APPLICATIONS IN IC TECHNOLOGY

The recent developments in Vertical Gallium Arsenide (GaAs) Channel High Electron Mobility Transistors (HEMTs) for power applications within Integrated Circuit (IC) technology have yielded promising results. Through extensive simulations and experiments, the Vertical GaAs Channel HEMTs have demonstrated notable advancements in key performance metrics. One of the significant outcomes involves the achievement of enhanced power efficiency, a critical parameter for power applications. The Vertical GaAs Channel HEMTs exhibit improved on-resistance characteristics, contributing to more efficient power handling. The simulations have revealed favorable outcomes in terms of high-frequency operation, aligning with the inherent capabilities of GaAs-based technologies in the millimeter-wave frequency range. This aspect is particularly valuable for applications such as wireless communication and radar systems.

Moreover, the simulations have validated the successful integration of Vertical GaAs Channel HEMTs into IC technology. The devices showcase compatibility with existing components, offering a pathway for seamless incorporation into integrated circuits. The power handling capability of these HEMTs has been a highlight, demonstrating their potential for high-power applications without compromising stability. The reliability and stability of the Vertical GaAs Channel HEMTs have also been a focus of the research. Simulations have assessed the devices' robustness under varying operating conditions, showcasing resilience to temperature fluctuations and voltage variations. These results instill confidence in the durability of the technology for real-world applications. In conclusion, the development of Vertical GaAs Channel HEMTs for power applications in IC technology has delivered encouraging results, marking a significant stride towards more efficient and high-performance electronic systems

V. Conclusions

The ongoing development of Vertical Gallium Arsenide (GaAs) Channel High Electron Mobility Transistor (HEMT) for Power Applications in IC Technology holds promising implications for the electronics industry. This innovation is anticipated to usher in improved power efficiency and performance, potentially leading to enhanced integration of power applications within compact integrated circuits. If successful, the technology may enable devices capable of operating at higher frequencies, particularly advantageous in communication and radar applications. Furthermore, the adoption of Vertical GaAs Channel HEMT could contribute to the ongoing trend of reducing power consumption in electronic devices, aligning with the growing demand for energy-efficient technologies. The potential applications of this technology extend to emerging fields like 5G communication and satellite technology, marking a significant stride toward more advanced and efficient electronic systems.

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