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GALLIUM NITRIDE SEMICONDUCTORS: TRANSFORMING THE TELECOMMUNICATION SYSTEMS POWER SUPPLY PERFORMANCE

This article presents a detailed review of the advancements in Gallium Nitride (GaN) technology, particularly emphasizing its transformative role in the development of power converter technology. The review starts by laying out the basic yet vital properties of GaN, such as its high electron mobility, wider bandgap, and superior thermal conductivity. These characteristics enable GaN to surpass the performance of traditional silicon-based devices, especially in applications that demand high-frequency operation. This introductory section aims to provide a clear, easily understandable explanation of why GaN stands out in the semiconductor world.

Building on this foundation, the article shifts its focus to the specific role of GaN in enhancing power converters, a critical component in various electronic devices. Here, it details the tangible improvements that GaN brings to the table, including increased efficiency, reduction in size, and better thermal management. The discussion centers around how these enhancements not only improve the performance of power converters but also contribute to the overall efficiency and compactness of electronic systems.

Moreover, the review explores the wider implications of the shift towards GaN in the realm of power electronics. It contemplates a future where efficiency and performance standards in electronic devices are redefined, thanks to the integration of GaN technology.

Finally, the article provides a comprehensive overview of both the current impact and the future potential of GaN semiconductor technology in the field of telecommunication power converters. It brings together various aspects of GaN technology – from its fundamental properties to its practical applications and future possibilities – offering a complete picture of how GaN is shaping the future of power electronics. This comprehensive approach makes the article an informative read for anyone interested in the latest trends and future directions in semiconductor technology.

Key words: *Gallium Nitride (GaN), power converters, wide bandgap semiconductors, high efficiency.*

Problem Statement. Silicon-based MOSFET devices are currently the standard in power switches for various power applications, including AC/DC and DC/DC supplies, and motor controls, covering a broad range of power levels from mere tens of watts to several thousands of watts. These devices have undergone continuous enhancements in critical parameters such as on-resistance $R_{DS(ON)}$, voltage ratings, switching speeds, packaging, and other features. However, the pace of improvements in silicon MOSFETs has reached a plateau, largely because their performance is now approaching the theoretical maximum, as dictated by the fundamental physics inherent to these materials and processes. Nevertheless, the recent advancements in the telecommunication power systems domain have been driven by the need for low power consumption, high efficiency, and power density.

This situation underscores the need to explore alternative wide bandgap materials like gallium nitride GaN and silicon carbide (SiC) to push the boundaries of power switch technology further.

Gallium Nitride (GaN), a wide bandgap semiconductor, has emerged as a highly effective solution for high-power transistors, especially at elevated temperatures. Initially gaining prominence in the 1990s for its application in blue light-emitting diodes (LEDs), GaN's use has since expanded to encompass semiconductor power devices, RF components, lasers, photonics, and sensor technology, showcasing its versatile potential. GaN's superior properties have made it a material of choice in these areas, underscoring its broad applicability [1].

The development of enhancement-mode GaN transistors, known as GaN FETs, in 2006 marked a pivotal advancement. These transistors are produced by growing a GaN layer on an Aluminum Nitride (AlN) buffer layer atop standard silicon wafers. This process, achieved through metal-organic chemical vapor deposition (MOCVD), aligns GaN transistor fabrication with the existing silicon component manufacturing infrastructure. This compatibility maintains cost-efficiency and eases integration due to the enhanced transistor performance, bridging the gap between new semiconductor materials and traditional manufacturing methods (Fig. 1) [2].

Analysis of recent research and publications. The usage Gallium Nitride (GaN) transistors has directed a new era in the telecommunication power supply systems. Characterized by their high efficiency and power density, GaN transistors are increasingly recognized as pivotal components in the evolution of modern power supplies.

The earlier research conducted by Saltanovs and Krainyukov (2018) marked a significant stride in the application of GaN transistors. Their study focused on the utilization of eGaN EPC2034 transistors in wireless power transmission systems, emphasizing the transistors' exceptional frequency properties and compactness. The creation of power inverter hybrid modules using these transistors and their subsequent efficiency assessment, particularly under direct liquid cooling with silicone oil, underscored the potential of GaN transistors in enhancing wireless power transmission efficiency [3].

Further advancing the understanding of GaN transistors, Lazarević et al. (2019) demonstrated a high-efficiency, high-bandwidth power supply system for linear power amplifiers. This system, leveraging the capabilities of GaN transistors, operated at a 1-MHz switching frequency and achieved efficiencies beyond 94% [4]. The study not only highlighted the efficiency benefits of GaN transistors but also their role in achieving fast switching speeds, thus reinforcing the importance of wide bandgap devices in power electronics.

In the context of power supply efficiency and density, Persson's research provided a comparative analysis of 600 V GaN transistors with high-performance Si FETs and SiC Schottky diodes. This comparison revealed how GaN technology could propel power supplies to new heights of efficiency and density, thereby setting a new benchmark in the field [5].

Lastly, the radiation hardness of GaN transistor-based power supplies was explored by Devine and Gonzalez (2020). Their research, focusing on the board-level testing of these power supplies in extreme radiation environments, confirmed the durability and consistent performance of GaN transistors under such conditions. This finding is particularly relevant for applications in compacted and harsh environments of special-use telecommunication devices, where robustness is critical [6].

Task statement. This article provides an overview of the advancements and applications of Gallium Nitride (GaN) technology in the telecommunications sector. It begins by elucidating the unique attributes of GaN, such as its high electron mobility and wide bandgap, which make it particularly suitable for high-frequency and high-power applications. This section aims to offer a foundational understanding of GaN's advantages over traditional silicon-based technologies.

The core of the article delves into the current applications of GaN in the telecommunications industry.

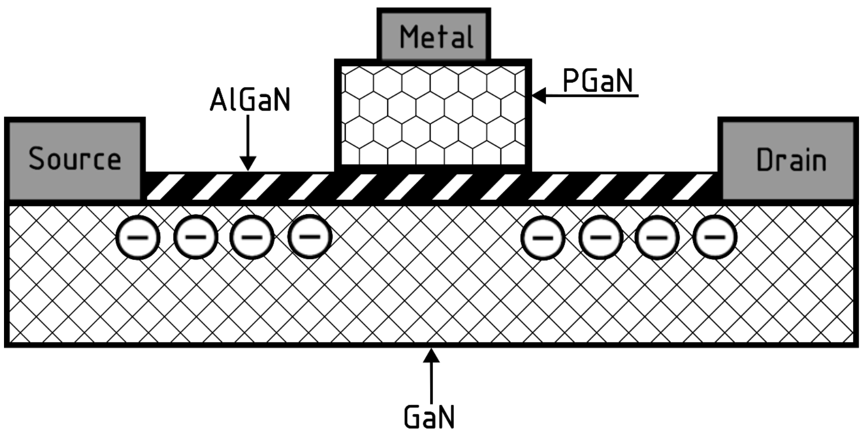

Fig. 1. GaN on an Aluminum FET structure

It highlights its significant role in power converters and RF amplifiers, which are integral to the efficiency and functionality of telecommunication systems. This segment emphasizes the practical implementations of GaN and the improvements they bring to the sector, such as enhanced signal quality, reduced power loss, and greater system reliability.

Further, the article explores the prospects of GaN in telecommunications. It presents an analysis of ongoing research, emerging trends, and potential innovative applications that could revolutionize the industry. This part of the article is particularly focused on how GaN technology might evolve and influence future telecommunications infrastructure, including 5G networks and beyond.

Lastly, the article touches upon the economic aspects of transitioning to GaN technology in telecommunications. It discusses the cost implications, market trends, and potential returns on investment, offering a comprehensive perspective on the economic impact of adopting GaN technology.

Outline of the main material of the study. A critical property of semiconductor materials is their bandgap, which determines their electrical conductivity. GaN's bandgap is 3.4 eV, significantly wider than silicon's 1.12 eV (Table 1). This attribute allows GaN to tolerate higher voltages and temperatures compared to silicon MOSFETs, making it ideal for high-power and high-frequency devices, as well as in optoelectronics, where these properties are crucial.

Table 1

Semiconductor material parameters

Material parameters			
Parameters	**Si**	**GaN**	**SiC**
Bandgap E_g, eV	1.12	3.39	3.26
Critical Field E_{crit}, MV/cm	0.23	3.3	2.2
Electron Mobility μn, $cm^2/V \cdot s$	1400	1500	950
Permittivity, ε_r	11.8	9	9.7
Thermal Conductivity λ, W/cm·K	1.5	1.3	3.8

GaN's efficiency in electron conduction and resilience to high electric fields surpasses silicon in terms of speed, temperature tolerance, and power handling. Consequently, GaN is increasingly supplanting silicon in various power conversion and RF applications. This transition is a testament to GaN's superior performance capabilities in these critical areas.

As can be seen from Figure 2, the theoretical on-resistance per unit area (R_{DS}(ON)) for $1mm^2$ power semiconductor devices is plotted against the blocking voltage for three different materials: Silicon (Si), Silicon Carbide (SiC), and Gallium Nitride (GaN). This graph provides a clear comparison of the materials' performance with respect to power efficiency at varying voltages.

Si, the traditional material for power devices, exhibits a steep increase in on-resistance with rising voltage, indicating higher power losses at elevated voltages. This makes Si less ideal for high-voltage applications. In contrast, SiC and GaN show a much more gradual increase in on-resistance with voltage. Their superior performance at high voltages is evident, which suggests they are more efficient, leading to lower energy losses.

The shallower slopes for SiC and GaN compared to Si's steeper slope highlight their better suitability for applications where voltage and on-state resistance requirements are particularly high. This makes them attractive for use in modern power systems where efficiency is a critical parameter, such as electric vehicles, communication systems, server power supplies, etc.

GaN's advantages extend beyond its electrical properties. Its fast-switching speed permits higher switching frequencies, leading to smaller passive component sizes and, in some cases, eliminating the need for mechanical heatsinking. This contributes to a significant reduction in size and weight in the final product when utilizing GaN FETs and ICs. The high switching performance and miniaturization offered by GaN result in unprecedented power density and efficiency across numerous applications, revolutionizing product design.

An important aspect of device operation is heat dissipation. GaN FETs demonstrate exceptional thermal performance, even with a smaller FET area compared to equivalent R_{DS}(ON) MOSFETs. For chip-scale GaN transistors, thermal resistance to the case (RθJC) is lower than that of silicon devices, ensuring efficient thermal conduction [3]. This improved thermal management is pivotal in maintaining device reliability and performance.

The GaN-based switching component ecosystem has evolved, comprising a broad array of devices, sophisticated modeling and simulation tools, specialized drivers, comprehensive application support, and extensive field experience. These developments propel GaN devices into performance realms beyond current and foreseeable MOSFET capabilities, marking a significant technological evolution.

However, the advanced capabilities of GaN devices require careful management of their operational characteristics, such as precise control over turn-on/off dynamics, gate drive requirements, voltage and current slew rates, current levels, noise sources and coupling, and layout considerations [7]. Therefore, integrating GaN technology in pow-

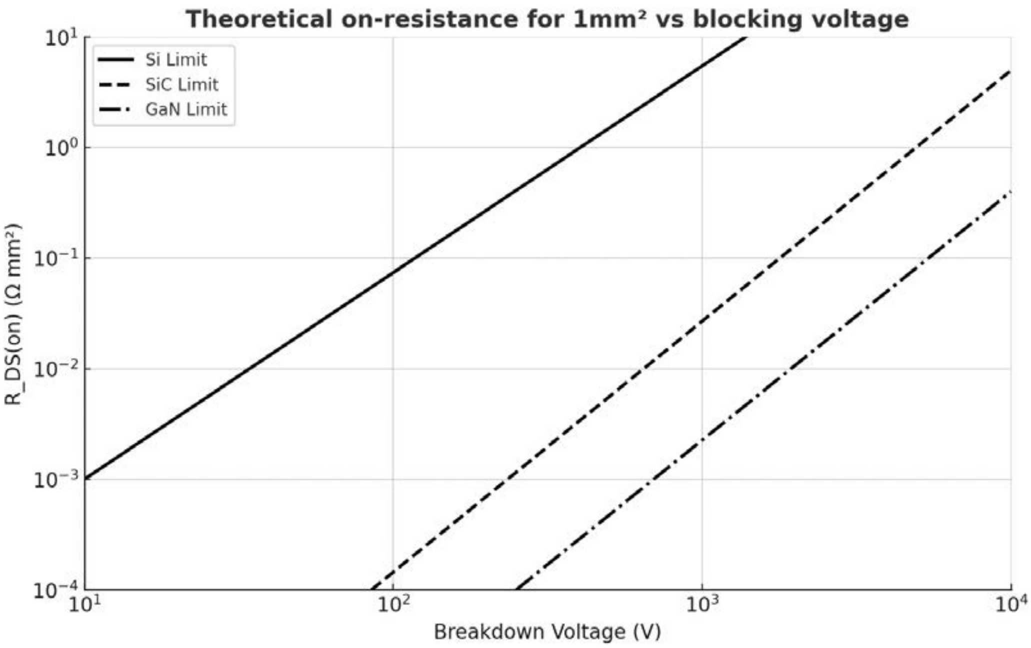

Fig. 2. Theoretical on-resistance for 1mm² vs blocking voltage

er-switching applications necessitates a nuanced, detailed engineering approach to maximize its potential while addressing associated challenges. This careful integration strategy is essential for harnessing GaN's full capabilities in various applications.

Conclusions. This article demonstrates the transformative impact of Gallium Nitride (GaN) technology in enhancing telecommunication power supplies. GaN's superior characteristics, such as high electron mobility, wide bandgap, and excellent thermal conductivity, make it a significant improvement over traditional silicon semiconductors, especially in high-frequency applications. These properties not only lead to increased efficiency but also enable a reduction in the size and improved thermal management of power converters and RF amplifiers in telecommunications systems.

The practical benefits of GaN are evident in real-world implementations, which showcase substantial improvements in the performance and compactness of power supply systems. Additionally, the compatibility of GaN with existing silicon fabrication processes facilitates a smoother transition to this advanced technology, balancing enhanced performance with cost-effectiveness. This aspect is crucial for its wider adoption in the industry.

Looking to the future, GaN is poised to play a pivotal role in the evolution of electronic devices, promising greater energy efficiency and higher performance. The ongoing research and development in this field suggest that GaN technology will not only revolutionize telecommunications but also find applications in various other sectors.

In summary, GaN semiconductors represent a major technological advancement, offering unprecedented improvements in the efficiency and capabilities of electronic devices. This shift from silicon to GaN is a key milestone in semiconductor technology, paving the way for more innovative and efficient electronic solutions in the future.

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Бурковський Я.Ю., Зіньковський Ю.Ф. ПЕРЕТВОРЮВАЧІ ЕНЕРГІЇ НА ОСНОВІ НІТРИДУ ГАЛІЮ (GAN): ТРАНСФОРМАЦІЯ СИСТЕМ ЖИВЛЕННЯ ТЕЛЕКОМУНІКАЦІЙНИХ СИСТЕМ

У цій статті розглядаються досягнення у сфері застосування широкозонних напівпровідників таких як нітрид галію (GaN) та його вплив на перетворювачі електричної енергії у системах живлення телекомунікаційного обладнання. Огляд починається з розгляду основних, але найважливіших властивостей GaN, таких як його висока рухливість електронів, ширша заборонена зона та висока теплопровідність, які перевершують такі у звичайних кремнієвих напівпровідників. Цей вступний розділ має на меті надати чітке та зрозуміле пояснення того, чому GaN виділяється у світі напівпровідників. Обговорення зосереджено навколо того, як ці вдосконалення не тільки покращують коефіцієнт корисної дії перетворювачів енергії, але й сприяють загальному вдосконаленню та зменшенню габаритів електронних систем. Як наслідок, використання GaN підвищує ефективність роботи силових елементів у високочастотних перетворювачах у порівнянні з кремнієвими аналогами. Стаття в першу чергу зосереджена на ролі широкозонних напівпровідників у вдосконаленні перетворювачів енергії, а саме їх КПД, розміру та температурних режимів. Огляд представляє поточний і потенційний майбутній вплив застосування широкозонних напівпровідників, таких як нітрид галію та карбід кремнію, на ефективність, габарити та тепловиділення високочастотних перетворювачів енергії. Нарешті, стаття містить вичерпний огляд як поточного впливу, так і майбутнього потенціалу технології GaN у сфері перетворювачів енергії для телекомунікаційних систем. Це дослідження розглядає різні аспекти технології GaN – від її фундаментальних властивостей до практичного застосування та майбутніх можливостей – оглядаючи повну картину того, як GaN формує майбутнє силової електроніки. Цей комплексний підхід робить статтю інформативною для тих, хто цікавиться останніми тенденціями та майбутніми напрямками в напівпровідникових технологіях.

Ключові слова: *нітрид галію (GaN), перетворювачі потужності, широкозонні напівпровідники, висока ефективність.*