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IMPLEMENTATION OF GAN DEVICE FOR HIGHLY EFFICIENT POWER AMPLIFIERS

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ABSTRACT: For use in the small amplifiers found in LTE base stations, Fujitsu is now working on gallium nitride high electron mobility transistors. The high breakdown voltage of GaN-HEMT makes it a popular choice for efficient transmitter amplifiers. Amplification at base stations must be efficient and have a high gain in order to save power and keep space to a minimum. Recent developments in the manufacture of a Gallium Nitride High Electron Mobility Transistor (GaN-HEMT) designed for Long-Term Evolution (LTE) base stations are thoroughly examined in this paper. The characteristics of power and high voltage are being studied in great detail. Before delving into the benefits of GaN-HEMT, let's take a look at its physical properties and how it's used in amplifiers. We lay out the current situation in detail and highlight the key points to remember when working with GaN-HEMT in its early phases. The following data shows the specifics of the power amplifier's efficiency. We carefully consider every conceivable scenario in the end.

***KEYWORDS*:** GAN-Based Power Amplifiers, Efficiency Enhancement, GAN-Optimized Power Transistors and RF Power Electronics.

1. INTRODUCTION

It is critical to enhance mobile wireless communication systems' transmission speeds and channel capacities due to the extensive usage of smartphones in Japan. A new generation of these systems is getting close to commercialization, and the rollout of LTE mobile wireless communication networks has already begun. Mobile wireless communication networks are made faster and more capable by base stations. In order to save money on maintenance and speed up system installation, they are crucial. To accomplish these aims, space-saving technology and efficient power use are crucial. An overview of the development and salient features of high-power transmitter amplifier technology is the goal of this essay. One major technical accomplishment by Fujitsu is the development of gallium nitride high electron mobility transistors (GaN-HEMTs), which significantly decrease power consumption and increase efficiency. Also, we look at what the future holds for the GaN-HEMT industry.

2. PHYSICAL PROPERTIES OF GAN

Blue and white light-emitting diodes (LEDs), made from gallium nitride, are utilized for a variety of lighting applications. These light-emitting diodes (LEDs) are popular among people due to their extended lifespan and minimal energy use. Table 1 shows how GaN and traditional semiconductors compare in terms of their physical characteristics. When compared to other semiconductors like silicon (Si) and gallium arsenide (GaAs), gallium nitride (GaN) possesses superior voltage capabilities. This is due to its increased resistance to breakdown when subjected to an electric field. Silicon (Si) chips are used in modern base station systems. The 48 V power level of the base station system is higher than the 28 V operating voltage of the high-power amplifiers. Various circuits within base station systems alter the electrical power's frequency. If base stations can minimize the amount of power voltage modifications they perform, they can optimize their size and energy efficiency. With a big energy band gap and a high resistance to electric field breakdown, gallium nitride (GaN) works well at high voltages. A 50-volt amplifier could be made using gallium nitride (GaN), which has a high breakdown voltage. This is beneficial because it lessens power loss caused by changes in voltage.

Because of its characteristics that enable fast electron migration and acceleration, gallium nitride (GaN) is perfect for attaining high-speed and high-efficiency performance. Even if heat is produced by powerful actions, silicon carbide (SiC) is more conductive to heat than gold and can distribute it more efficiently. To begin fixing this, we utilize it as a foundation. The enhanced comprehension is a direct outcome of GaN's physical qualities, which allow it to function effectively at high voltages and energies.

Table 1 Comparison of physical property of GaN with othermaterials.

Material	Breakdown electric field (MV/cm)	Heat conductivity (W/cm/K)	Traveling electron density (/cm²)	Mobility (cm²/Vs)	Saturated electron speed (cm/s)
Si	0.3	1.5	Up to10^{17}	1300	1×10^{7}
GaAs	0.4	0.5	Up to10^{17}	2000-4000 (MESFET)	1.3×10^{7}
SiC	3.0	4.9	Up to10^{17}	600	2×10^{7}
GaN	3.0	1.5	Up to10^{17}	1500 (HEMT)	2.7×10^{7}

High breakdown voltage High-voltage operation | High-current-density operation High-temperature operation | High-speed operation High-efficiency operation

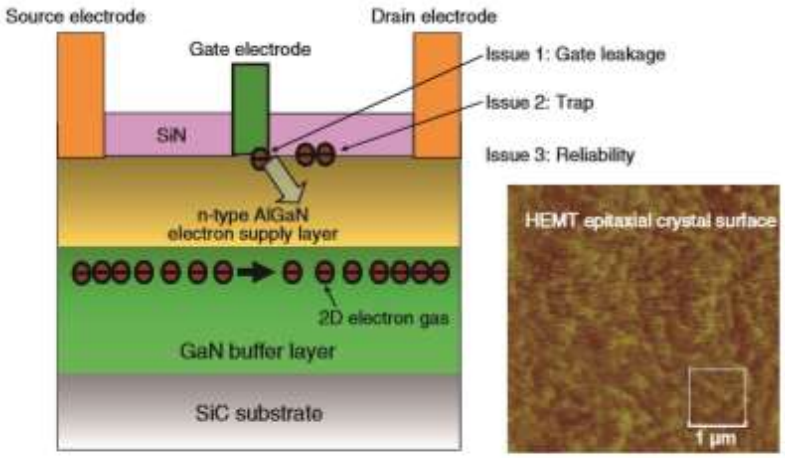
3. GAN-HEMT STRUCTURE ANDDEVELOPMENT ISSUES

A high electron mobility transistor (HEMT) takes advantage of the fact that semiconductor materials with different band gaps have better electron mobility than regular semiconductors to create a field-effect

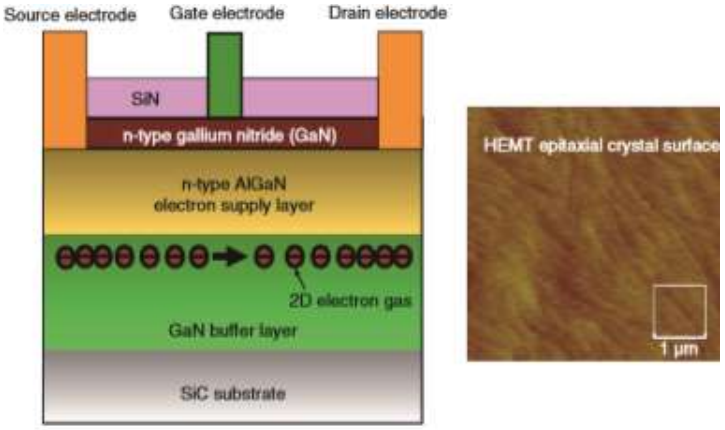
transistor. The use of compound semiconductor GaAs in HEMT was first introduced by Fujitsu in 1980. It is presently widely used as technology for an IT society's infrastructure, such as in mobile phones, GPS navigation systems, and wireless access networks that cover large areas.

Figure 1(a) shows the HEMT structure, which consists of two layers of GaN and AlGaN arranged separately. It uses a 2D electron gas, which are moving electrons, that is created in the junction to function. The HEMT structure can achieve a higher current density than the field-effect transistor topologies often found in devices based on Si and GaAs. The strong internal electric field generated by Gallium Nitride's (GaN) intrinsic spontaneous and piezoelectric polarizations causes it to display a piezoelectric action. Therefore, compared to conventional compound semiconductor materials like GaAs, the creation of a 2D electron stream can be enhanced tenfold, resulting in a higher current density. As a result, it is possible to outperform conventional transistors in terms of power and operational efficiency. Because of these features, GaN amplifiers are seen as very promising next-generation high-power amplifiers. Figure 1 (a) shows the difficulties that were discovered during the early 2000s when the HEMT structure was first used for high-voltage operation.

1. It is unacceptable for the gate electrode to generate such a high level of gate leakage current.
2. When operating at high frequencies and powers, the device undergoes electron entrapment, resulting in an increase in on-resistance and, finally, a collapse in current.
3. If power is applied consistently for an extended period of time, power performance may decline or fail unexpectedly.
4. These limitations made the transistor unstable and unsuited for high-voltage applications.



(a) Conventional GaN-HEMT structure



GaN-HEMT design including charge management and a recessed ohmic surface

Figure 1 structure and surface topology of GaN-HEMTs.

This is aided by the surface structure (atomic force microscopy) depicted in Figure 1a. The Grand Canyon is visible in the uppermost fissures.

4. GAN-HEMT DEVELOPMENTTECHNOLOGIES

Figure 1 (b) Outlines the transistor configuration designed to address the issues mentioned before. Improving the surface topology and reducing gate leaks have mostly focused on managing the connection between the GaN-HEMT and the gate electrode. As a result, we proposed a structure that responds to changes in surface charge. An n-type doped GaN layer is superimposed atop the HEMT structure in this design, allowing it to transport electricity. As can be seen in Figure 1(b), the proposed design effectively prevented surface fractures. To enhance the ohmic characteristics, this technique employs a high-density top layer, which is significantly different from conventional GaAs-based devices. Despite the presence of doping impurities, all high-density electrons have been utilized.

The distribution of the electric field inside the device was determined by the simulation. According to the findings, the standard configuration featured an area surrounding the gate electrode with an extremely high electric field. The gate is leaking because of the strong electric field. We have optimism for reducing gate leakage thanks to the novel structure that controls surface charge. It inhibits any electric field development at the gate electrode. The surface of the semiconductor does not now include any easily oxidized aluminum. Potentially, this might prevent the current from crashing due to surface electron traps.

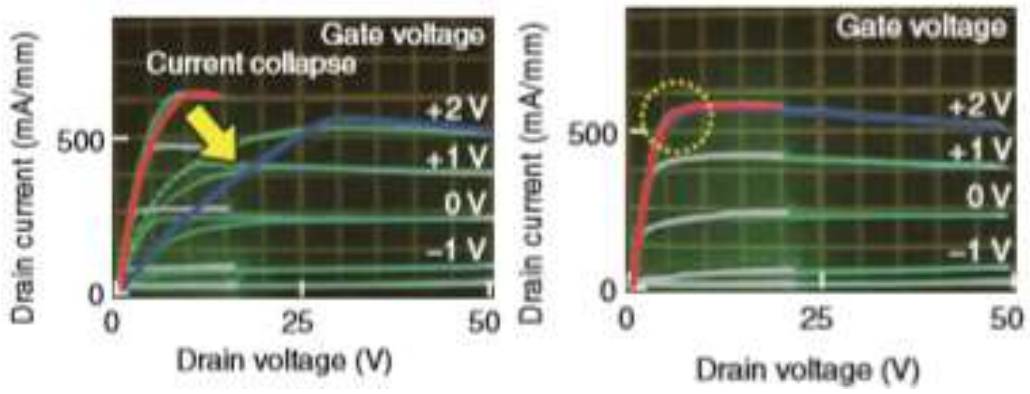
The GaN-HEMT device was created by the authors using metalorganic vapor phase epitaxy (MOVPE). Because of its excellent heat conductivity, SiC was chosen as the basis material. A SiC substrate was covered with n-type GaN cap, n-type AlGaN electron supply, and GaN buffer layers using the MOVPE technique. Reduced resistance due to ohmic contact was achieved using an approach known as inset ohmic technology. In order to do this, the ohmic electrode portions must have their n-type GaN cap layers removed, and the electrodes must be constructed directly on top of the AlGaN electron supply layer. The power was increased by maintaining the gate length at 0.5 µm and covering the GaN surface with a silicon nitride (SiN) passivation layer. The device's reliability is improved by reducing gate

leakage and current collapse using the aforementioned methods. With this new method, the issue of fast failure can be resolved by reducing the gate leakage to 1/1000th or less of the typical construction.

The worsening of a current collapse is seen in Figure 2. The graph displays the relationship between current and voltage. The measurements were taken at a 100 Hz frequency using a curve tracer. Both the conventional and authors' structures are depicted in Figure 2(a and 2(b, respectively). The drain current increases significantly with increasing drain voltage, as seen in Figure 2(b). So, the on-resistance growth is limited. Improving the quality of the GaN buffer layer allows it to better manage power characteristic fluctuations during extended power generating periods. Thanks to this discovery, GaN-HEMT is now a commercially available product that is being offered globally for the first time.

5. GAN-HEMT AMPLIFIER

As seen in Table 2, GaN-HEMT amplifiers have many advantages. Ordinary devices have a low impedance compared to the ideal impedance, which increases as the working voltage does. Consequently, circuit matching is a breeze. Harmonic processing can be made simpler to get more efficiency. Furthermore, less heat emission may lead to a smaller physical footprint.



(a) Operation with conventional structure (b) Operation with present structure developed

Figure 2 I-V curves of GaN-HEMT.

Table 2 Advantages of GaN-HEMT amplifier.

Physical property	Advantage of HEMT	Advantage of amplifier
• High breakdown voltage	• High-voltage operation • High load impedance • Good linearity	• Easy harmonic processing (higher efficiency) • Low matching loss • Simplified voltage conversion
• Wide band gap	• High-temperature operation	• Small, lightweight cooling system
• High heat conductivity • High current density	• High-voltage operation • Small chip size	• Small, lightweight amplifier

Figure 3 The amplifier showcased features adjustable fixtures and utilizes a GaN-HEMT chip with a

gate breadth of 36 mm. The functional need of the device was to enhance W-CDMA signals for third-generation mobile phone base stations. It achieved this by operating at 63 volts and 174 watts.A push-pull amplifier was constructed by paralleling two of these devices, resulting in a peak output of 250 W. The amplifier was operated with W-CDMA signals at 50 V (3), 4. Additionally, a distortion compensation circuit based on digital pre-distortion (DPD) was incorporated. GaN-HEMT's high load impedance makes it a promising option for distortion compensation, as it can attain a 40% efficiency in single-end average power operation. The utilization of these facilitating technologies has made it highly feasible to produce amplification with an average operational efficacy of 50%.

6. FUTURE OF GAN-HEMT

Figure 4 Displays, at the appropriate frequencies, the anticipated market path for goods based on GaN-HEMT. Successfully commercializing and transforming into lucrative firms, the authors' inventions were utilized to produce base station applications, mostly in the 2 GHz range. Additionally, there is a need to enhance efficiency for future base station applications. The ability to process harmonics in GaN-HEMT makes it useful in many amplifier circuit topologies and enables it to accommodate a wider bandwidth. It is considered a promising foundational technology for future .

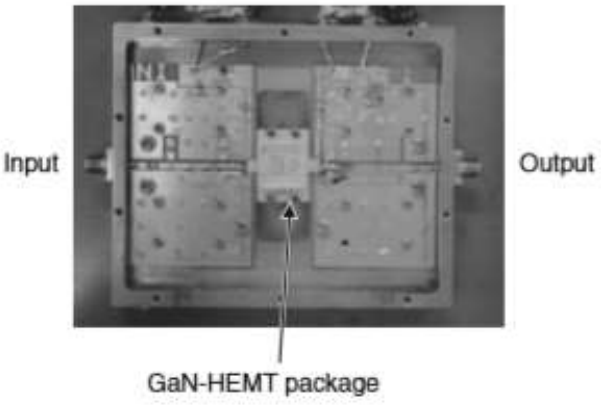


Figure 3
GaN-HEMT power amplifier.

We also anticipate expansion into additional bandwidths. HaN-HEMT is an alternative to high-frequency band amplifiers, particularly those operating at millimeter-wave frequencies.Table 1 shows an amplifier application that takes use of the high speed of GaN. Its possible applications include long-distance wireless communications in mountainous areas and emergency situations. A high-efficiency power supply system operating in the kilohertz to megahertz frequency range is expected to make extensive use of these amplifiers in switching transistors. The key reasons for this are the HEMT structure's extremely fast switching speed and the increased breakdown voltage enabled by the intrinsic physical properties described in Table 1. A smaller and more efficient power source, such as a PC AC adapter, is one expected effect. Transistors are predicted to play an important role in electric vehicles and photovoltaic power generation in the future, as these applications will require a highly efficient

power source

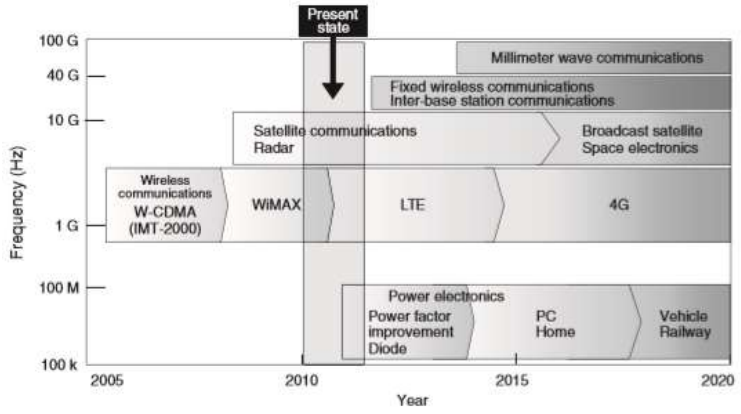


Figure 4 Technological developments in GaN-HEMTs, or gallium nitride high electron mobility transistors, are in the works.

It is expected that GaN-HEMT would be utilized for purposes other than amplifiers in base stations in the future, and multiple power supply units are commonly used in these facilities.

7. CONCLUSION

A surface charge-controlled device's current collapse and gate leakage were significantly reduced after the researchers added a conductive n-type GaN layer. This puts us ahead of the curve when it comes to the world's ability to produce 250 watts at 50 volts. The authors not only created history by bringing GaN-HEMT to market first, but they also improved GaN's physical properties and came up with new ways to prove the material's trustworthiness. We have already completed large-scale manufacture of GaN-HEMTs designed for use in LTE base stations through our prior efforts. Researchers hope to speed up the development of GaN-application HEMTs and put them to use in base stations.

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