Journal of Ovonic Research Vol. 19, No. 1, January – February 2023, p. 81 - 86

Electron confinement enhancement in AlGaN/AlN/GaN HEMT using BGaN buffer

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When the AlGaN/GaN high electron mobility transistor (HEMT) is strongly biased, the speed of the electrons in the channel increases, which leads to an injection of electrons into the buffer, and consequently the appearance of the "short channel effect" phenomenon, which limits the performance of the component to overcome this effect and increase the power/frequency performance of the component, one solution consists in using a confinement barrier. This involves placing an electrostatic barrier under the GaN channel so as to block the injection of electrons into the buffer layer when the transistor is highly biased, and a BGaN confinement barrier because this semiconductor has very interesting physical properties, as well as better electrical isolation between the well and the substrate thanks to the optimization of the buffer. In this paper, the main objective is to study the effect of adding BGaN confinement barrier and its influence on transistor performance.

(Received December 9, 2022; Accepted February 1, 2023)

*Keywords:*AlGaN/GaN, BGaN back-barrier, Optimization,Power/frequency.

1. Introduction

Improving the power-frequency performance of high electron mobility transistors is not solely based on technological improvements such as gate length reduction and passivation. Indeed, another very important point is to reduce the thickness of the barrier separating the gate from the channel as the gate length decreases, in order to reduce the transit time, and therefore the access to high frequencies of higher transition. But for this situation, it appears a harmful phenomenon of the type "punch-through" or effect of the short channel, because of the low confinement of the electrons in the channel, which negatively affects the performance of the component. To overcome this effect, one solution is to use containment barriers. This involves placing an electrostatic barrier under the GaN channel to block the injection of electrons into the buffer when the transistor is highly polarized. several studies have been done, for example the study of S. Rennesson[1,7,8] on HEMTs with AlGaN and InGaN containment barrier. The AlGaN confinement barrier slightly increases the dislocation density in the GaN HEMTs structures and decreases the carrier density in the two-dimensional gas as well as the electron mobility, resulting in a drastic increase in sheet resistance. the InGaN confinement barrier does not modify the surface morphology of the HEMTs, whatever the type of substrate, it makes it possible to block the electrons in the channel, thus

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https://doi.org/10.15251/JOR.2023.191.81

improving the confinement of the two-dimensional gas, but not necessarily the modulation of the current (hence the transconductance) because the buffer leak was high.

As it stands, it is still difficult to conclude on the choice of the type of containment barrier to be used for high frequency power applications. But there are many problems that can be overcome by incorporating into these structures a new element; boron, among the studies recently developed, in connection with the development of suitable substrates in GaN mesh parameter, the boron element seems to be an original way to achieve this challenge.

The growth of boron nitrides remains difficult, however, and requires greater technological maturity to increase the boron content. Due to a large miscibility gap, the theory predicts a maximum value of 5% boron in BGaN[2,6]. Numerous studies yielded up to 3.6% composition using MOCVD growth [3] and 4.6% using MBE growth [4]. Nevertheless, it has been shown that very interesting properties are observable with only a few percentages. For example, when a few boron percentages are incorporated, boron nitrides, for example BGaN, have all the distinguishing characteristics of nitride-based materials [5].

2. Device structure and characteristics

2.1. Device structure

The AlGaN/GaN HEMTs under investigation are grown on silicon (111) substrate by using molecular beam epitaxy (MBE) (present some high purity). The active layers consist in a 500nm thick of undopedAlN/AlGaN buffer, a 1.8µm undopedGaN channel, a 23nm thick of undoped $Al_{0.26}Ga_{0.74}N$ barrier and a 1nm n+-GaN cap layer. The device processing is made following conventional HEMT fabrication steps. The ohmic contact pads are patterned using e-beam lithography. Hereafter, the metallization by means of evaporated 12/200/40/ 100nm Ti/Al/Ni/Au is deposited at 900°C during 30s. The Schottky gate is realized using 100/150nm Mo/Au layers with a length of 0.25µm. The gate-source distance is 0.77µm and that of the gate-drain is 1.32µm.

2.2. Structure optimization

To increase the power / frequency performance of the component, we have placed a thin layer of BGaN as an electrostatic barrier under the GaN channel so as to block the injection of electrons into the buffer layer when the transistor is strongly polarized (Fig.1).

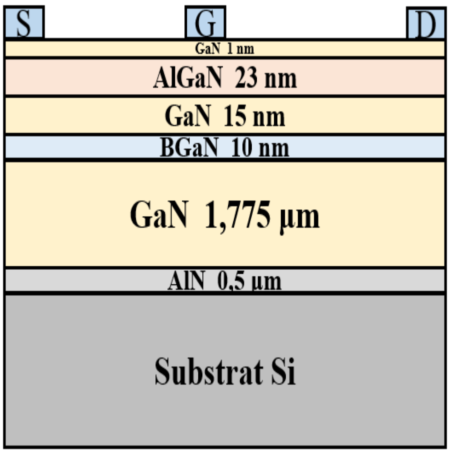


Fig. 1. Optimized structure of the AlGaN / GaN HEMT transistor with BGaN back-barrier.

As shown in figure-2, the incorporation of the BGaN layer into the HEMT structure under the channel creates a conduction band discontinuity ΔE, which induces an electric field in the channel at the interface with the barrier confinement due to polarization difference in this region.

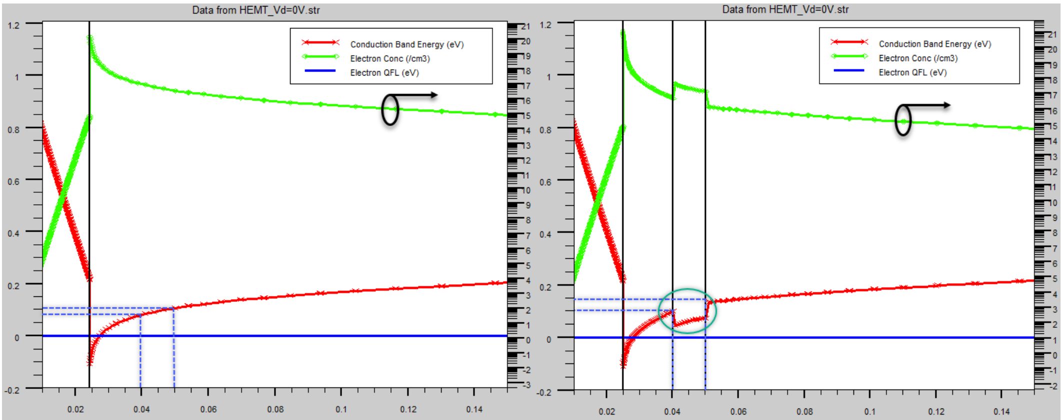


Fig. 2. Conduction band and electron concentration of an AlGaN / GaN HEMT transistor with and without the BGaN containment barrier.

As indicated in this figure, the incorporation of the BGaN layer in the HEMT structure under the channel creates a conduction band discontinuity ΔE, which induces an electric field in the channel at the interface with the confinement barrier because of difference of polarization in this region.We notice an increase in conduction band energy in the new structure of the HEMT transistor, for example:

$$x(ZCE)= 0{,}04\ \mu m, Ec_{(AlGaN/GaN)} =0{,}08\ eV\ et\ \ Ec_{(AlGaN/GaN/BGaN)} =0{,}1\ eV$$

$$x(ZCE)= 0{,}05\ \mu m, Ec_{(AlGaN/GaN)} =0{,}1\ eV\ et\ \ Ec_{(AlGaN/GaN/BGaN)} =0{,}15\ eV$$

In the same figure, the maximum value of the electron concentration in the 2DEG gas in the standard structure at the AlGaN / GaN interface is approximately $3.55.10^{21}$ cm-3, unlike in the new structure at the AlGaN interface / GaN is higher and is about 1.10^{22} cm-3, which shows that this layer prevents diffusion and leakage of electrons to the substrate. Thus, the BGaN rear barrier improves the confinement of the two-dimensional electronic gas on the one hand because this layer improves the energy band diagram; and on the other hand, it increases the resistivity of the structure under the channel.With this type of material, a larger wall can be obtained to block the electrons using either a thicker BGaN layer or a monolayer which gives higher confinement.

2.3. DC characteristics

After incorporation of the BGaN as a confinement barrier (FIG. III-17), a slight decrease in the threshold voltage of -3.7 V to -3.9 V is observed in the transfer characteristics Ids (Vgs). which increases the carrier density of 2DEG. In addition, the output characteristics Ids (Vds) in the same figure indicate that the negative conductance is canceled as well as the maximum current Ids (max) reached 0.5 A after it was equal to 0.4 A. He got a 25% increase. This leads to an increase in the power performance of the component [6].

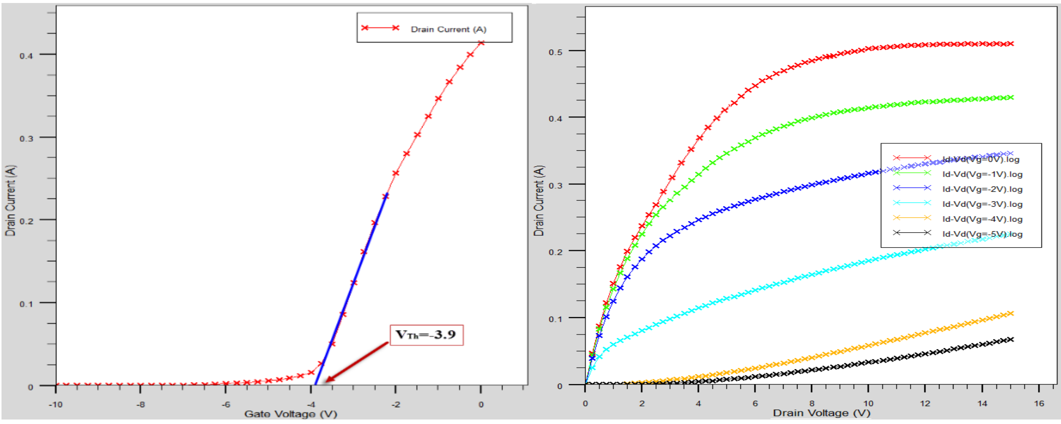
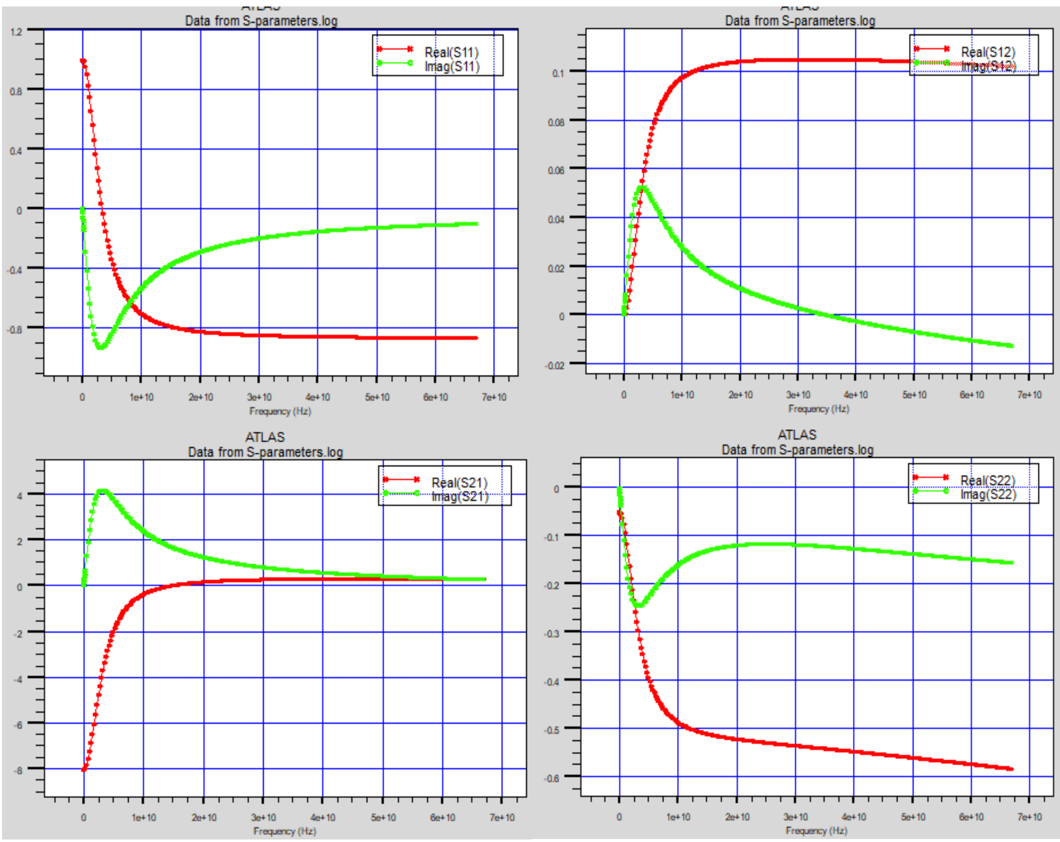


Fig. 3. Transfer and output characteristic of AlGaN / GaN HEMT transistor with BGaN back- barrier

2.4. ACcharacteristics

The measurement or simulation of the S parameters is an important step to estimate the RF performance of the power component and to extract the different parameters of the linear model. In the framework of our study of Al0,26Ga0,74N / GaN components, we present the S11 and S22 output reflection coefficients, as well as the S12 and S21 transmission coefficients.



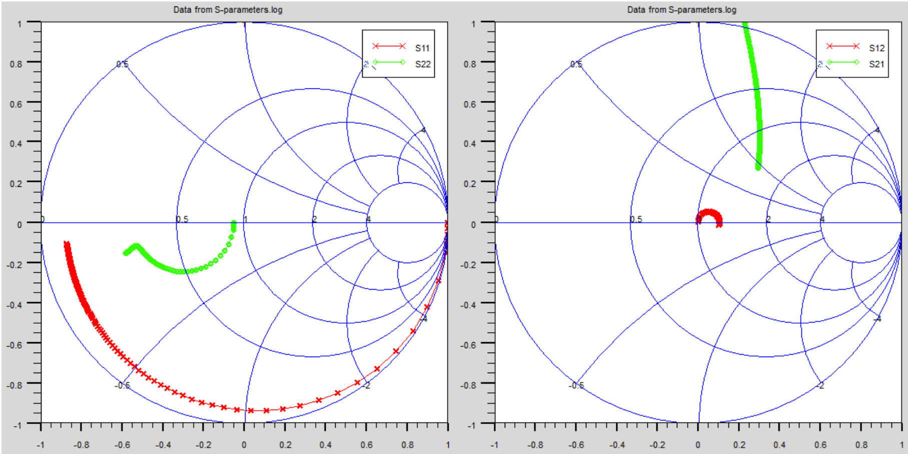


Fig. 4. S-parameters of AlGaN/GaN/BGaN/GaN HEMT.

It is also observed in fig.5 that the incorporation of BGaN as a confinement barrier improves the frequency parameters of the AlGaN / GaN HEMT transistor. Indeed, the transition frequency has achieved an increase of 52%, it reaches 30 GHz. In addition, the frequencies Fmax and Fmsg are respectively reached at 100 GHz and 103 GHz, which implies that this new structure improves the frequency performance, it can operate at frequencies up to several tens of gigahertz.

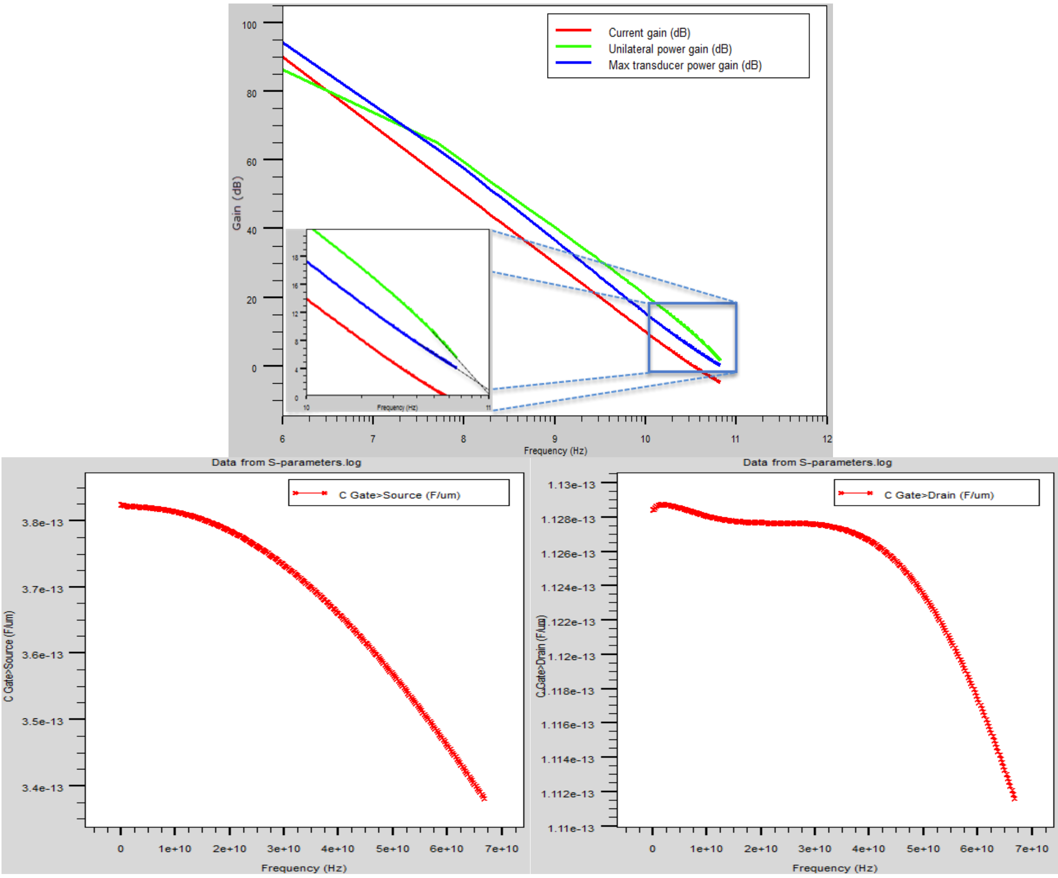


Fig. 5. Gain of AlGaN/GaN/BGaN/GaN HEMT.

3. Conclusion

The study focused on the BGaN confinement barrier, allowed us to notice that this new alloy achieves astonishing results, where it increases the confinement of the 2D gas, it is the main objective, but without effects which would lead to limit the component performance. The BGaN back-barrier increases the density of carriers in the two-dimensional gas but also the mobility of electrons, this resulting in a drastic increase in power performance. Moreover, it increases the frequency limits of the standard HEMT structure and makes it more stable. Although these new materials have only been studied by a few groups, several results are expected. Indicating that these innovative structures are very promising for the next generations of high power and high frequency applications.

Acknowledgments

This research has been funded from Research Deanship in University of Ha'il – Saudi Arabia through project number RG-21 140.

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