J Biochem Tech (2018) Special Issue (2): 141-144
ISSN: 0974-2328

A new Design and Simulation of AlGaN/GaN HEMT for Using in High Frequency Structures

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Received: 25 February 2018 / Received in revised form: 25 May 2018, Accepted: 29 May 2018, Published online: 05 September 2018

Abstract

In this paper, a new structure of transistor AlGaN/GaN high electron mobility transistor (HEMT) is presented. The proposed structure is implemented on a regular HEMT layer wafer. In this structure, the creation of a new layer Si_3N_4 on the initial structure was used to improve the frequency response and the impurity oxide layer to improve the flow efficiency. The proposed structure has a current rate of 140 dB at a cutoff frequency of 800 GHz, which is much improved with respect to the original structure as well as other structures presented in this regard. For a better comparison, two models of HEMT are simulated by the Silvaco TCAD software, which includes a normal HEMT model, and the other incorporating an improved HEMT by adding an impurity layer in it. The proposed simulation of this structure makes it possible to use it in high-frequency circuits.

Key words: HEMT, Cutoff, Current rate, Bandwidth, GaN, AlGaN, Si_3N_4

Introduction

Today with the advancement of technology, the transmitter, satellite receivers and integrated circuits require higher power generation, higher frequency, better linear performance and higher efficiency. The mentioned factors motivate the development of semiconductor devices in order to meet the specified specifications with the related costs. Consequently, designers have made significant advances in the semiconductor industry in order to meet the growing needs of high-performance communication systems, including high-mobility electron transistors (HEMTs) (Morkoc & Solomon, 1984; Hao & et al, 2018). In recent years, the design and development of HEMT-based on GaN has attracted a lot of attention due to its unique properties and high performance (Raab & et al, 2003; Mateos & et al, 2000)

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GaN is a semiconductor material that has many features, including high electron mobility, high failure voltage and high frequency (Krämer, 2006; Hamm & Ghannouchi, 2009). Also AlGaN/GaN has a heterogeneous structure and has a wide band gap (Mishra & et al, 2002; Du & et al, 2017). For this reason, this material is the best option for high power applications and low noise amplifiers, and has good performance at high frequencies, which is very useful for designing HEMT (Cheng & Zhang, 2015; Kobayashi, Denninghoff & Miller, 2016).

In this article, we are designing and reviewing a new HEMT. In this structure, the cutoff frequency is about 800 GHz, the current gain 140 dB and the drain current in this structure are about 60 μA, which is much better than the similar structures in this field. In order to make design more comfortable and easier, it was originally designed by a normal HEMT and then major improvements were made to improve the structure's results. The corrections made to add the layer of Si3n4 to improve the frequency response and also to add impurity oxide in the structure are used to improve the flow efficiency.

The rest of the paper is organized as follows: In Sect. 2, include of simulation normal HEMT. Sect 3, a new structure for proposed structure is presented, and finally, the conclusions are presented in Sect.4.

Simulation of normal HEMT

In order to better understand how to design the desired structure optimization, a normal HEMT structure is simulated first, as shown in Fig. 1. According to the presented form, the structure consists of two different layers. The under layer is a substrate of the GaAs form and the upper layer is a channel with a thickness of 22 nm and a thickness of AlGaAs (Wang & et al, 2014). Fig. 2, shows the drain current of this structure, according to which the maximum current of this transistor is 50 μA. Also in Fig. 3, shows the frequency response diagram of this structure, which, according to its maximum current gain, is 100 dB, and its bandwidth is 0.9 THz.

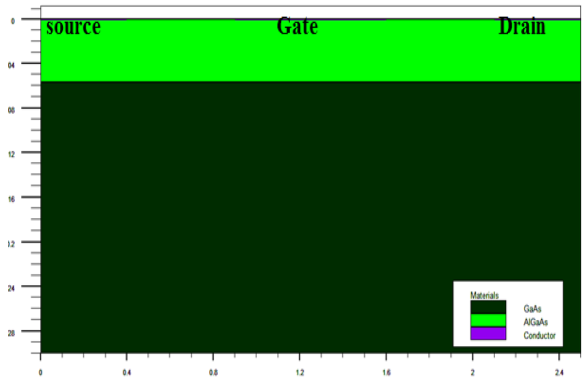

Figure 1. Normal GaAs/AlGaAs HEMT model.

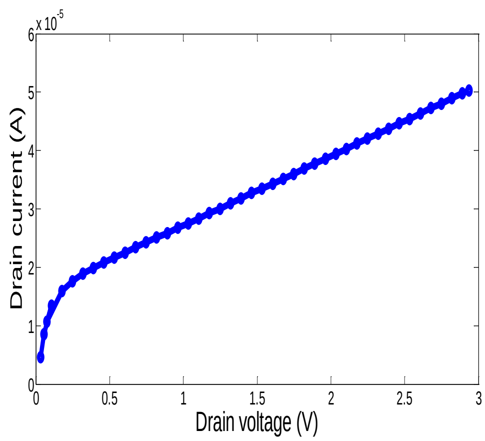

Figure 2- Drain current diagram of Normal GaAs/AlGaAs HEMT.

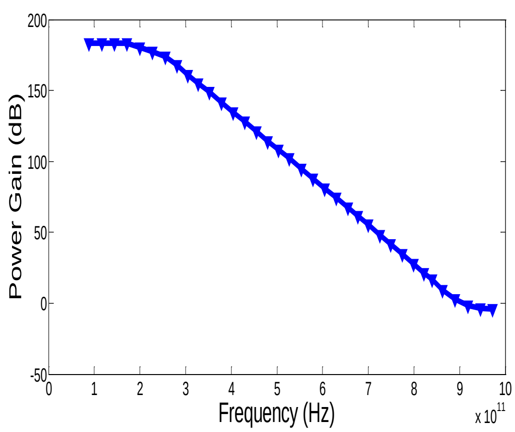

Figure 3- Frequency response of Normal GaAs/AlGaAs HEMT.

A new design of performance HEMT

The new structure wafer, which is designed here, is similar to the normal HEMT structure shown in Fig. 4. In this structure, a Si_3N_4 layer is used above the structure and a layer GaN and AlGaN. The use of Si_3N_4 in the structure has led to an improvement in the frequency response. An oxide layer in the body has also been used to reduce current losses and thereby increase the current of the proposed structure, which can lead to significant improvements in structure with increasing mobility and reducing leakage simultaneously.

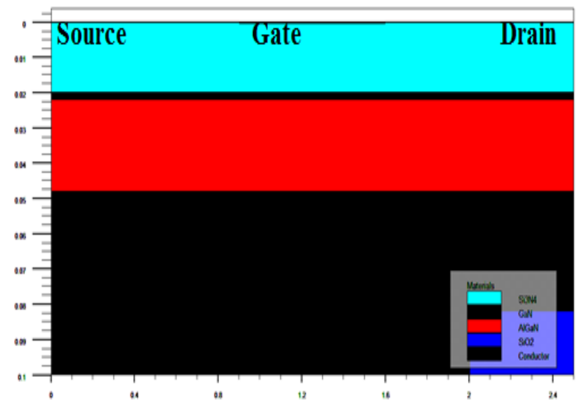

Figure 4- The proposed GaN/AlGaAs HEMT model.

The current-voltage diagram of the proposed structure is shown in Fig. 5. According to the presented form, the current of this structure is 30 µA. In order to improve the performance of the proposed structure, the displacement of impurities in this structure has been used. The general schematic of this structure is shown in Fig. 6.

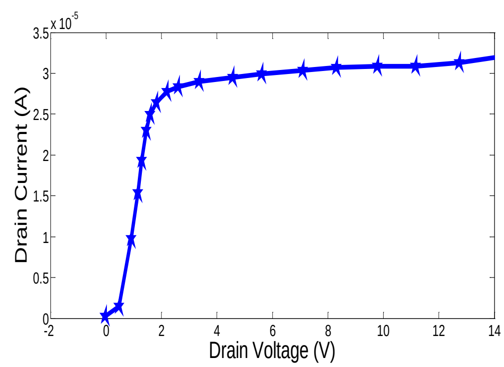

Figure 5 - Drain current diagram of proposed GaAs/AlGaAs HEMT.

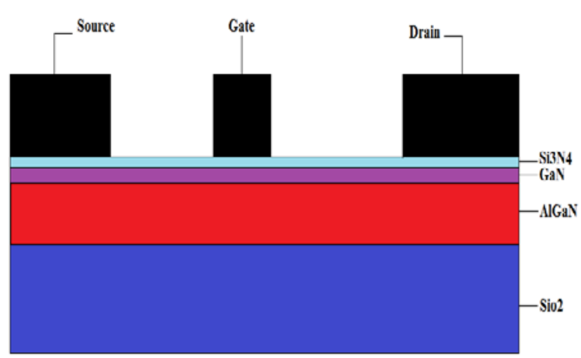

Figure 6 -Schematic proposed GaAs/AlGaAs HEMT.

With the displacement of impurities in the structure, the transistor current has increased dramatically and has doubled to about 60 μA in relation to the structure before it. Fig. 7, shown the current-voltage diagram of this proposed structure. The cutoff frequency of this structure is 800 GHz and its current gain is 140 dB, which is higher than the previous structures, as shown in Fig. 8.

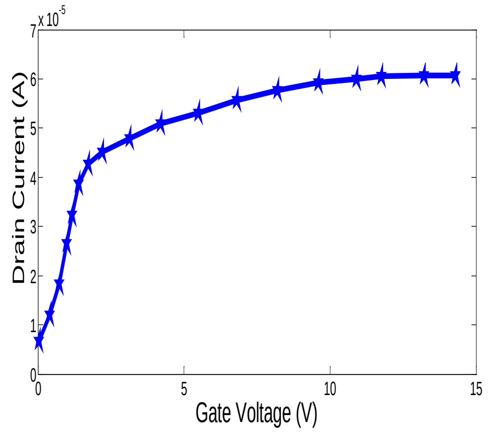

Figure 7- Drain current diagram of improvement proposed GaAs/AlGaAs HEMT.

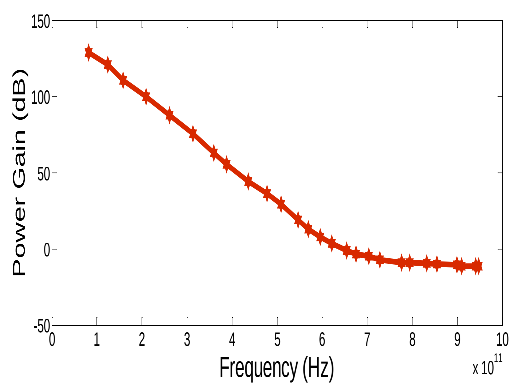

Figure 8- Frequency response of improvement proposed GaAs/AlGaAs HEMT.

Various parameters including drain current, current gain and cutoff frequency of the proposed structure with other structures presented in this field are presented in Table 1. According this table, proposed structure has better outcomes than other structures, especially since our structure has a dramatic increase in current rates, which is a very practical advantage for use in high-speed circuits.

Table. 1- Comparison between different parameters of the proposed structure with other structure

Structure	Cutoff frequency	Interesting current	Drain current
proposed structure	800 GHz	140 dB	60 μA
Normal HEMT	900 GHz	100 dB	50 μA
(Wang & et al, 2014)	460 GHz	40 dB	16 μA
(Shinohara & et al, 2013)	180 GHz	35 dB	20 μA
(Chung & et al, 2010)	50 GHz	60 dB	50 μA

Conclusion

In this paper, a new structure for the HEMT is provided to improve current efficiency and increase current. In order to design this structure, this work has been done on a normal HEMT and has undergone changes that, in terms of manufacturing, also have such an idea and structure to be implemented. In the proposed structure of the Layer Si_3N_4, in order to improve the frequency response and a layer of impurity oxide, to reduce current losses and increase the current rate. The proposed structure of the ratio of other structures has better results, such as the very high current gain that can be used by high-speed circuits. On the other hand, it seems that due to the very acceptable outcomes, the preliminary structure of work on such an idea and the continuation of this very good way will lead to significant results.

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