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High Electron Mobility Transistor (HEMT) Device for detection of Biomolecules: Recent Developments

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Abstract

In this article, we focus on the recent developments of the detection of the biomolecules using the high-electron-mobility transistor(HEMT). Generally the detection of biomolecules using traditional assays is a very complex process which requires specially trained experts and the process is also time consuming in nature. On the other hand biosensors have a tremendous potential for obtaining standard and accurate information from biomolecules in a faster and simpler manner. Due to their inherent material properties such as higher electron mobility, two-dimensional electron gas (2DEG), chemical inertness, stability at high temperatures, and high speed, HEMTs have shown to have more potential and enormous benefits among various biosensors. This article discusses the fundamental ideas of HEMT-based biosensors in terms of structure, techniques, and the significance of biomolecules.

Keywords : HEMT, Biosensor, 2DEG

1. Introduction

The high electron mobility transistor (HEMT) is a heterostructure field effect device. The most-common heterojunctions for the HEMTs are the AlGaN/GaN, AlGaAs/GaAs, AlGaAs/InGaAs and InAlAs/InGaAs heterointerfaces. Figure 1 shows a schematic view of a conventional AlGaN/GaN HEMT. The main feature of a HEMT is its heterojunction structure. For the HEMT in Figure 1, AlGaN is the wide bandgap semiconductor and GaN is the relatively low bandgap semiconductor. A two-dimensional electron gas(2DEG) layer forms at the hetero interface of AlGaN/GaN high electron mobility transistor(HEMT). The benefits of high electron mobility transistor (HEMT) based sensors include increased mobility and the formation of two-dimensional electron gas (2DEG), which increases sensitivity and minimizes the risk of static electricity damage[1].

Because of their low cost, repeatable, and predictable electrical response, silicon-based sensors remain the most common, dominating, and readily accessible semiconductor material. The major disadvantage of these sensors is that they are not appropriate for use in harsh conditions such as high temperatures, high pressure, or corrosive environments. Wide bandgap group III nitride compound semiconductors are an alternative to Silicon-based sensors because of their chemical resistance, high temperature or high power capabilities, and high electron saturation velocity[2, 3].

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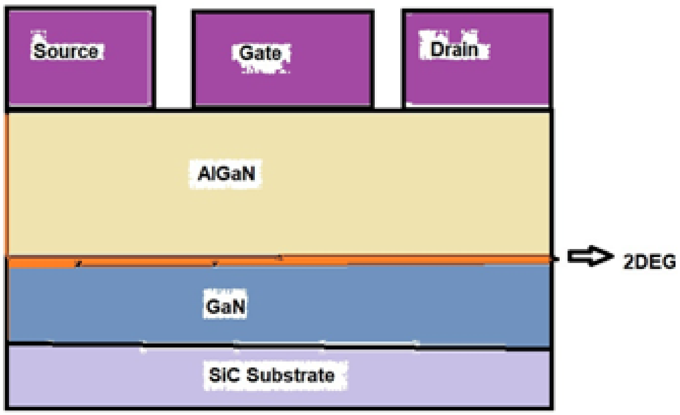

Figure 1 : Conventional schematic structure of AlGaN/GaN HEMT

2. Mechanism

The working concept is based on the biomarker's mechanism and the participation of biomolecules in the device. When the device comes into contact with a higher concentration of biomolecules, the electrical characteristics of the device, such as electron concentration, drain current, and threshold voltage, all change significantly.

3. Structure

Recent studies show that the addition of an ultra-thin AlN spacer layer between AlGaN and GaN, with a thickness of 1 nm (less than the critical thickness of 2DEG), enhances the 2DEG density by removing charge carriers from the barrier AlGaN layer[4, 5]. The presence of an AlN exclusion layer results a significant conduction band offset at the hetero interface which improves the device performance in terms of current, frequency, and power. The structure of developed model of two-dimensional cross sectional AlGaN/AlN/GaN HEMT biosensor for detection of biomolecules has shown in Figure 2 [6].

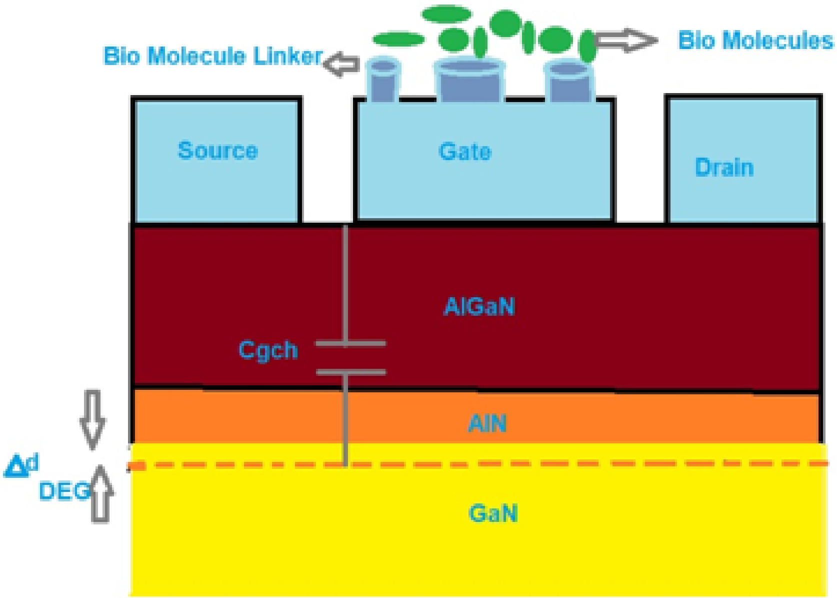

Figure 2 : Two-dimensional cross sectional AlGaN/AlN/GaN HEMT biosensor for detection of various biomolecules

4. Sensor Model

The output drain current is dependent on the gate bias , according to the charge control model[6]. When biomolecules are immobilized, their impact on device properties will be neutralized by the imposed gate bias. As a result, a floating gate model is necessary to fully assess the effect of channel/2DEG modulation owing to gate immobilization rather than gate biasing. The biomolecule poses a certain charge depending on its condition. So due to these charged biomolecules on tha gate a capacitive effect will be felt in the heterojunction layer. As a result more electrons will be accumulated in the 2DEG region for positively charged biomolecules. Similarly electrons will be dissipated for negatively charged biomolecules on the gate due to capacitive effect. Increased electron density in the channel will lead to enhancement of drain current and decreased electron density thereby leading to a decrease in the drain current.

5. Performance of HEMT Based Biosensor in Comparison with Silicon Based Biosensor

Silicon(Si) based biosensor require higher gate charge as well as high bias gate voltage(10-12 V) whereas GaN HEMT biosensors require lower gate charge which decreases driving loss and enables faster switching and to get on state source drain resistance it requires low bias gate voltage(5-6 V). Due to low gate voltage and low output capacitance GaN HEMT are better for high bandwidth applications such as fast switching. Silicon biosensor has a low saturation velocity but GaN HEMT has a high saturation velocity which results in low loss for power devices. GaN HEMT has a capability to operate on a very high temperature but Silicon biosensor can't. In respect of Silicon biosensor, GaN HEMT offers comparatively higher efficiency[7-11].

6. Conclusion

AlGaN/GaN, AlGaAs/GaAs based HEMT biosensor has wide range of properties such as increased sensitivity, strong selectivity, specificity, reliability, stability, good repeatability, linearity, chemical and thermal stability, high electron mobility, and reduced device size. These overspread properties ensure the effectiveness of the HEMT device as a biosensor. This groundbreaking biosensor technique has a wide range of applications in biomedical engineering, including pathogen and toxin detection, transplant rejection, troponin I, cell differentiation, early illness diagnosis and prognosis, drug development, medicine, and cellular dynamics research. Detection of cardiovascular disease, protein, DNA, glucose, pH values of solution is possible by this technology. This technique offers a reduction in the cost and time, is simple to integrate into portable systems, and shows promise as a point-of-care diagnostics in the future.

References

[1] Podolska, Anna, et al. "Cell growth and attachment to AlGaN surfaces for biosensor applications." 2010 International Conference on Nanoscience and Nanotechnology. IEEE, 2010.

[2] Wen, Xuejin, et al. "Improved sensitivity of AlGaN/GaN field effect transistor biosensors by optimized surface functionalization." IEEE Sensors Journal 11.8 (2010): 1726-1735.

[3] Thapa, Resham, et al. "Biofunctionalized AlGaN/GaN high electron mobility transistor for DNA hybridization detection." Applied Physics Letters 100.23 (2012).

[4] Li, Tao, Ravindra P. Joshi, and Romeo D. Del Rosario. "Requirements for low intermodulation distortion in GaN-Al/sub x/Ga/sub 1-x/N high electron mobility transistors: a model assessment." IEEE Transactions on electron devices 49.9 (2002): 1511-1518.

[5] Hsu, L., and W. Walukiewicz. “Effect of polarization fields on transport properties in AlGaN/GaN heterostructures.” Journal of Applied Physics 89.3 (2001): 1783-1789.

[6] Varghese, Arathy, Chinnamuthan Periasamy, and Lava Bhargava. “Analytical modeling and simulation-based investigation of AlGaN/AlN/GaN Bio-HEMT sensor for C-erbB-2 detection.” IEEE Sensors Journal 18.23 (2018): 9595-9603.

[7] Libertino, Sebania, et al. “Feasibility studies on Si-based biosensors.” Sensors 9.05 (2009): 3469-3490.

[8] Libertino, S., et al. “Biosensor integration on Si-based devices: Feasibility studies and examples.” Sensors and Actuators B: Chemical 179 (2013): 240-251.

[9] Tikhomirov, V. G., et al. “The sensitivity research of multiparameter biosensors based on HEMT by the mathematic modeling method.” Journal of Physics: Conference Series. Vol. 917. No. 4. IOP Publishing, 2017.

[10] Li, Xiaobin, et al. “A comparative study of GaN HEMT and Si MOSFET-based active clamp forward converters.” Energies 13.16 (2020): 4160.

[11] Pal, Praveen, et al. “Open gate AlGaN/GaN HEMT biosensor: Sensitivity analysis and optimization.” Superlattices and Microstructures 156 (2021): 106968.