The sensitivity research of multiparameter biosensors based on HEMT by the mathematic modeling method

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Abstract. The numerical impact modeling of some external effects on the CVC of biosensors based on AlGaN/GaN heterostructures (HEMT) was carried out. The mathematical model was created that allowed to predict the behavior of the drain current depending on condition changes on the heterostructure surface in the gate region and to start the process of directed construction optimization of the biosensors based on AlGaN/GaN HEMT with the aim of improving their performance. The calculation of the drain current of the biosensor construction was carried out to confirm the reliability of the developed mathematical model and obtained results.

1. Introduction
It was proposed to use heterostructures AlGaN/GaN (HEMTs) without the gate to create multiparameter biosensors by many authors [1-3]. The absorption of biological molecules on the gate region causes the new charge state of the surface that affects the flow of current in two-dimensional channel of the HEMT. Thus, the adsorption of molecules controls current drain-source similarly to classic gate.

2. Simulation results
Different coats (platinum, gold, etc.) in the form of droplet or solid films are suggested for the selective adsorption of biological molecules on the gate region. Nitrides of metals of the 3rd group – semiconductors allowed the creation of the new devices of opto- and microelectronics with unique characteristics, were considered as the most promising semiconductor material for these biosensors. An example of such biosensor is shown in Figure 1. It is important for invasive biosensors that devices based on GaN, AlGaN have exceptional chemical and temperature resistance. The temperature resistance is ensured not only by the properties of semiconductor material but also by contact resistance of the drain-source.
Nowadays the reliable confirmation of the impact of heterostructure parameters and its surface state on the performance of the multibiosensors based on HEMTs without the gate continues to be complex, time-consuming and costly procedure.

The numerical impact modeling of some external effects on the CVC of biosensors based on AlGaN/GaN heterostructures (HEMT) was carried out in the framework of the present study. Well-known software packages for the numerical modeling of semiconductor devices were used as basic tools for the modeling and the optimization of HEMTs [4]. The simulation results were compared with the experimental results of electrophysical parameters measurement of heterostructures and HEMTs. Figure 2 shows a schematic cross section of the base of AlGaN/GaN HEMTs with a fragment of the estimated region of the transistor for the numerical modeling.

Before considering of calculation results, it should be discussed about some important problems and ways to solve them for multiparameter biosensors based on GaN HEMT. The authors of modern scientific articles [5-8] propose several constructive solutions providing high sensitivity and easy
operation of biosensor. For example, it is suggested using biosensor construction with the coat of the gold in the gate area and special acid (thioglycolic acid) to determine the presence of heavy metals ions in researched liquid.

Several authors bring the sequence of technological operations to get finished biosensor design on the silicon substrate, in particular, with plating of Ti and Ag/AgCl [6]. The researchers proposed a planar design providing both the comfortable deposition of researched liquid in the area between source and drain and getting small quantities of the metallization resistance of electrodes to maintain a high sensitivity predicted in laboratory experiments or using the mathematical modeling. It is especially interesting for the possibility of the mathematical modeling of biosensors based on AlGaN/GaN HEMT that there is a change of GaN surface potential when the pH value of the sample at the gate changes.

Thus, authors of article [8] considered 3 designs of biosensors based on AlGaN/GaN HEMT and received the dependence of surface potential on the heterostructure border from the pH value of the liquid put in the gate area for all 3 variants.

It was possible due to the obtained results to create mathematical model that allows to predict the behavior of the drain current depending on condition changes on the heterostructure surface in the gate region, in particular, application of an electrolyte with known pH value, and in addition, allows to start the process of directed construction optimization of the biosensors based on AlGaN/GaN HEMT with the aim of improving their performance.

The calculation of drain current of the biosensor construction described and researched in [8] was carried out to confirm the reliability of the developed mathematical model and obtained results. Figure 3 shows the results of mathematical modeling with the potential on the drain 0.5 V and the experimental research data obtained in the aforementioned study. Mathematical modeling predicted the sensitivity of the biosensor at 80 µA/pH that was confirmed by experimental data. According to the results of the researched and the mathematical modeling the planar design of biosensors with different distance of the source-drain and metallization with gold, see Figure 4.

![Figure 3](image_url)

**Figure 3.** The dependence of the drain current change on the pH value of the sample at the gate. Circles show values predicted using of mathematical modeling.
3. Conclusion
The results of accomplished studies state the following. Numerical calculations allowed to suggest that the impact of specified external factor (location of electrolyte with known pH at the gate) on the CVC of researched device exists and this dependence has a monotonous character. More researches are needed for directional changes of the heterostructure and of the overall design of the biosensor to increase the sensitivity in the considered cases and to expand the range of detectable substances.

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