Studies of the operation of the biosensor surface based high electron mobility transistor AlGaN/GaN

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***Abstract*- Performance biosensor surface are often controlled by the rate of administration of the analyte to the detection surface instead of detecting sensors intrinsic capacitances. On the surface, carries analyte diffuses the biosensor surface severely limiting its performance. At low concentrations, this limitation, commonly known problem of mass transport, causing extremely long detection time ranging from a few days to a few months. In this instance, we propose and demonstrate a biosensor platform is based on a high-mobility transistor electronic AlGaN / GaN.**

Promising detection technology used AlGaN / electron transistors high mobility (HEMT GaN) as a biological sensor. HEMT structures have been developed for use in biological and biomedical domain because of their high gas two-dimensional electron (2DEG) mobility and saturation velocity. The 2DEG channel line AlGaN / GaN HEMT is very close to the surface and extremely sensitive to the adsorption of analytes.

In this paper we review recent progress on functionalizing the surface of HEMTs for specific detection of glucose, kidney marker injury molecules, prostate cancer, and other common substances.

Keywords-AlGaN/GaN; 2DEG; HEMT; analyte; gate.

INTRODUCTION

Wide bandgap GaN and related compound semiconductor materials possesses attractive chemical inertness and bio-compatibility for bio-sensor application. In particular, the AlGaN/GaN heterostructure features polarization induced high density two dimensional electron gas (2DEG) at the heterojunction that is only ~20nm below the surface. Since any surface modifications such as change to surface states, attachment of charged particles can affect the 2DEG density that ultimately can be detected by electrical measurements. Thus, numerous bio-sensors have been successfully implemented using the AlGaN/GaN 2DEG conduction as the sensing element [1-2]. In these previous works, several rounds of chip washing need to be conducted after the analyte incubation or immobilization in order to remove the unwanted or unbound analyte from the sensing area. To develop complete functional bio-sensing systems, it is highly desirable to develop ways of manipulating and delivering the bio-molecules and cells to the designated sensing area. In this regard, there has been no report on GaN based manipulating system suitable for bio-sensing application. In this work, we propose a GaN-based manipulation system based on the properties of 2DEG .

The 2DEG density is modulated by changes in the surface potential of the HEMT and thus, devices without gate metallization directly sense charged particles and molecules adsorbed onto the exposed gate area [3–4]. For these reasons AlGaN/GaN HEMT devices are subject of intense investigation and have emerged as attractive candidates for pH and ion sensitive sensors or detectors for biological processes [5–6]. In this work, we investigate the different technological steps for sensor fabrication to various biological substances.

II. BIOSENSOR FABRICATION

The HEMT structures in Fig. 1 typically consist of a 3 µm thick undoped GaN buffer, 30 Å thick $Al_{0.3}Ga_{0.7}N$ spacer, and a 220 Å thick Si-doped

$Al_{0.3}Ga_{0.7}N$ cap layer. The epilayers are grown on thick GaN buffers on sapphire substrates. The gate area of HEMT is functionalized with different chemicals depending on the sensing applications [7].

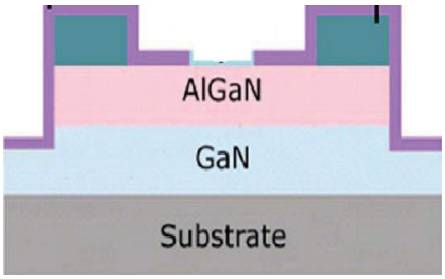

Figure1. schematic of HEMT.

Table 1 shows a summary of the surface functionalization layers we have employed for HEMT sensors to date. There are many additional options for detection of biotoxins and biological molecules of interest by use of different protein or antibody layers. The advantage of the biofet approach is that large arrays of HEMTs can be produced on a single chip and functionalized with different layers to allow for detection of a broad range of chemicals or gases [8].

TABLE.1 SUMMARY OF THE SURFACE FUNCTIONALIZATION

Detection	Mechanism	Surface functionalization
H_2	Catalytic dissociation	Pd,Pt
Pressure change	Polarization	Polyvinylidene difluoride
Botulinum toxin	Antibody	Thioglycolic acid/antibody
Proteins	Conjugation/hybridization	Aminopropylsilane/
pH	Adsorption of polar molecules	Sc_2O_3, ZnO
KIM-1	Antibody	KIM-1 antibody
Glucose	GO_x immobilization	ZnO nanorods
Prostate-specific antigen	PSA antibody	Carboxylate succimdyl ester/PSA antibody
Lactic acid	LO_x immobilization	ZnO nanorods
Chloride ions	Anodization	Ag/AgCl electrodes; InN
Breast cancer	Antibody	Thyioglycolic acid/c-erbB antibody
CO_2	Absorption of water/charge	Polyethylenimine/starch
DNA	Hybridization	Thiol-modified oligonucleotides
O_2	Oxidation	InGaZnO
Hg2+	Chelation	Thioglycolic acid/Au

III. EXEMPLE OF BIOSENSOR

A. Kidney injury molecule detection

The functionalization scheme in the gate region began with thioglycolic acid followed by KIM-1 antibody coating [9]. The gate region was deposited with a 5-nm thick Au film. Then the Au was conjugated to specific KIM-1 antibodies with a self-assembled monolayer of thioglycolic acid. The HEMT source-drain current showed a clear dependence on the KIM-1 concentration in phosphate-buffered saline (PBS) buffer solution

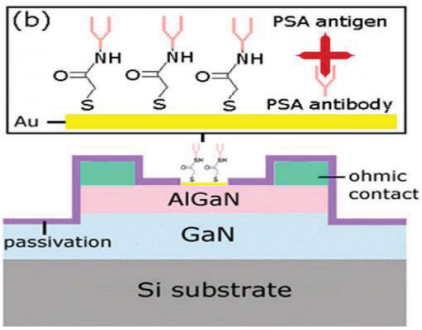

Figure 2. Schematic of HEMT sensor functionalized for PSA detection.

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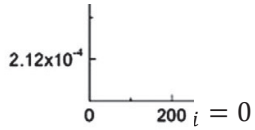

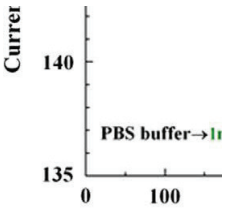

Figure 3. Drain current versus time for PSA detection when sequentially exposed to PBS, BSA, and PSA

B. Breast cancer

Antibody-functionalized Au-gated AlGaN/GaN high electron mobility transistors (HEMTs) show promise for detecting c-erbB-2 antigen. The c-erbB-2 antigen was specifically recognized through cerbB antibody, anchored to the gate area. We investigated a range of clinically relevant concentrations from 16.7 lg/ml to 0.25 lg/ml.

The Au surface was functionalized with a specific bi-functional molecule, thioglycolic acid. We anchored a self-assembled monolayer of thioglycolic acid, HSCH2COOH, an organic compound and containing both a thiol (mercaptan) and a carboxylic acid functional group, on the Au surface in the gate area through strong interaction between gold and the thiol-group of the thioglycolic acid. The devices were first placed in the ozone/UV chamber and then submerged in 1 mM aqueous solution of thioglycolic acid at room temperature.

This resulted in binding of the thioglycolic acid to the Au surface in the gate area with the COOH groups available for further chemical linking of other functional groups. The device was incubated in a phosphate-buffered saline (PBS) solution of 500 lg/ml c-erbB-2 monoclonal antibody for 18 h before real time measurement of c-erbB-2 antigen.

After incubation with a PBS buffered solution containing c-erbB-2 antibody at a concentration of 1 lg/ml, the device surface was thoroughly rinsed off with deionized water and dried by a nitrogen blower. The source and drain current from the HEMT were measured before and after the sensor was exposed to 0.25 lg/ml of c-erbB-2 antigen at a constant drain bias voltage of 500 mV. Any slight changes in the ambient of the HEMT affect the surface charges on the AlGaN/GaN. These changes in the surface charge are transduced into a change in the concentration of the 2DEG in the AlGaN/GaN HEMTs, leading to the slight decrease in the conductance for the device after exposure to c-erbB-2 antigen. Fig. 4 (top) shows real time c-erbB-2 antigen detection in PBS buffer solution using the source and drain current change with constant bias of 500 mV. No current change can be seen with the addition of buffer solution around 50 s, showing the specificity and stability of the device. In clear contrast, the current change showed a rapid response in less than 5 s when target 0.25 lg/ml c-erbB-2 antigen was added to the surface. The abrupt current change due to the exposure of c-erbB-2 antigen in a buffer solution was stabilized after the c-erbB-2 antigen thoroughly diffused into the buffer solution. Three different concentrations (from 0.25 lg/ml to 16.7 lg/ml) of the exposed target c-erbB-2 antigen in a buffer solution were detected. The experiment at each concentration was repeated five times to calculate the standard deviation of source-drain current response. The limit of detection of this device was 0.25 lg/ml c-erbB-2 antigen in PBS buffer solution. The source-drain current change was

nonlinearly proportional to c-erbB-2 antigen concentration, as shown in Fig. 4 (bottom). Between each test, the device was rinsed with 1 M KCl, pH 6.0, phosphate buffer solution containing a wash buffer of 10 to strip the antibody from the antigen.

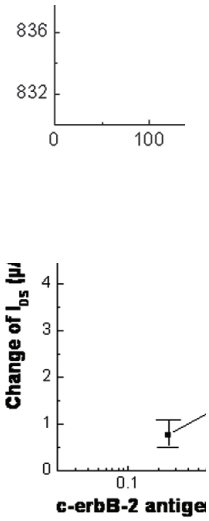

Figure 4. Drain current of an AlGaN/GaN HEMT over time for c-erbB-2 antigen from 0.25 lg/ml to 17 lg/ml (top) and change ofdrain current versus different concentration from 0.25 lg/ml to 17 lg/ml of c-erbB-2 antigen

Clinically relevant concentrations of the c-erbB-2 antigen in the saliva and serum of normal patients are 4–6 lg/ml and 60–90 lg/ml, respectively. For breast cancer patients, the c-erbB-2 antigen concentrations in the saliva and serum are 9–13 lg/ml and 140–210 lg/ml, respectively. Our detection limit suggests that HEMTs can be easily used for detection of clinically relevant concentrations of biomarkers. Similar methods can be used for detecting other important disease biomarkers and a compact disease diagnosis array can be realized for multiplex disease analysis[8].

IV. CONCLUSION

In conclusion, we showed a biosensor using a robust HEMT AlGaN/GaN These devices can take advantage of the advantages of microelectronics, including high sensitivity, possibility of high-density integration, and mass manufacturability. The goal is to realize real-time, and inexpensive

There is great promise for using AlGaN/GaN HEMT based sensors Depending on the immobilized material, HEMT-based sensors can be used for sensing different materials. These electronic detection approaches with rapid response and good repeatability show potential for the investigation of airway pathology. The high surface area (gate) provides an ideal approach for enzymatic detection of biochemically important substances.

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