Role of sensing parameters in Breast Cancer detection using GaN HEMTs

Shruti Mittal[1, 2], Ishit Makwana[1, 2], Nitin Chaturvedi[2], Nidhi Chaturvedi[1*]

[1]*CSIR-Central Electronics Engineering Research Institute, Pilani, India*
[2]*Department of Electrical & Electronics Engineering, Birla Institute of Technology and Science, Pilani, India*
[*]*Corresponding author's e-mail: nidhichatur@gmail.com*

Abstract

AlGaN/GaN HEMT is a promising device for detection of breast cancer, which operates on the principle of specific binding of c-erbB-2 protein through bio-functionalized layers of Gold and Thioglycolic acid applied on the gate region. In this paper, a simulation based study of the effect of various sensing parameters on device sensitivity is performed using nextnano3 simulation tool. These parameters include interface charge densities, thioglycolic acid concentration and c-erbB-2 concentration. The simulated device exhibits high current sensitivity of the order of 100 µA/mm for 20 µg/ml change in c-erbB-2 concentration in saliva, under practical environmental conditions.

Keywords: High electron mobility transistors, biosensor, cancer detection, sensing parameters, c-erbB-2.

Introduction

Recent studies indicate that saliva based testing for markers of breast cancer, such as the protein c-erbB-2, using GaN High Electron Mobility Transistors (HEMTs) based sensors, offer a very sensitive and reliable method for diagnostics of breast cancer [1]. Performance of these types of sensors is not only decided by the HEMT device design but also by several sensing parameters. In this article, we discuss detailed simulations of the c-erbB-2 HEMT sensor for breast cancer detection by studying the effect of various sensing parameters such as thioglycolic acid concentration, interface charge densities at AlGaN surface and variation in c-erbB-2 concentration.

Experimental

A GaN HEMT structure used for simulation was exposed to an electrolyte solution through a surface functionalization layer of Gold. A Gold layer was deposited over the gate region of HEMT which was then exposed to the saliva. The Gold layer was functionalized with a thioglycolic-acid (TGA) monolayer which allowed for specific binding of c-erbB-2 protein molecules, a biomarker in breast cancer detection. Due to strong interaction between gold and the thiol group, gold-sulphur (Au-S) bonds were formed at the gold surface which allowed for specific adsorption of c-erbB-2 molecules present in saliva solution [1]. The interaction of charges produced due to chemical linking of c-erbB-2 changed the potential at the Gold/AlGaN interface which acted as gate bias and varied the 2DEG density, thus forming a highly sensitive device for detection of c-erbB-2. The TGA was modeled as an oxide layer with a static dielectric constant ε_r=1.5. The saliva solution was modeled as an electrolyte consisted of various constituent ions of saliva. To account for the interface reactions at the electrolyte/TGA interface, a site binding model was considered for oxide surfaces [2], where the adsorption and dissociation of H+ and OH- ions at the electrolyte/TGA interface leads to formation of interface charge densities. These interface charge densities produced an interface potential at electrolyte/TGA interface which linearly varied with the pH of the electrolyte due to change in the ion concentrations. This effect formed the basis of the pH sensing of ion content in saliva. A series of experiments were performed where the effect of various sensing parameters such as interface densities, varying TGA concentration and c-erbB-2 concentration on the potential and current sensitivity of the device were studied. The simulation results were mainly focused on the pH range 6 to 8 which is the relevant pH range of saliva for breast cancer detection.

Results and Discussion

A. Effect of Interface Charges: Interface charges at AlGaN/Gold and Gold/TGA interfaces enhanced the sensitivity of the gate potential of HEMT as shown in Fig. 1. It was observed that the interface potential decreased with pH when interface charges were present at the AlGaN/Gold and Gold/TGA interfaces while it did not change when the interfaces charges were not considered. At a particular pH the gate potential was higher for the case with interface charges. The charge density at the interfaces altered the band bending in the TGA, Gold and AlGaN layers, reflecting the change in potential at electrolyte/TGA interface, according to the nonlinear Poisson-Boltzmann equation. Thus sensitivity of gate potential at AlGaN/Gold interface increased with interface charges.

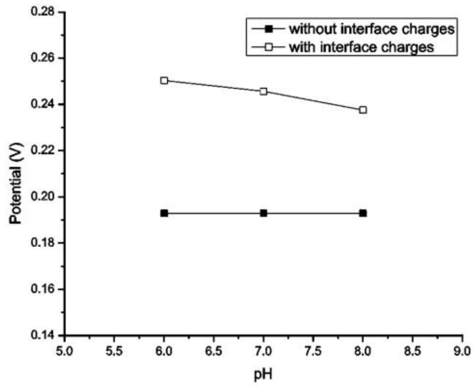

Fig. 1: Interface Potential at AlGaN surface as a function of pH, for the two cases

B. Effect of Thioglycolic concentration: The concentration of the TGA was increased gradually in terms of thickness (2 nm to 10 nm) and energy levels were checked. It was observed that as the thickness of TGA increased from 2 nm to 6 nm the potential drop across TGA layer increased which lead to higher band energy at AlGaN/Gold interface. However as the thickness of TGA was further increased from 6 nm to 10 nm the potential drop across TGA decreased which lowered the band energy at AlGaN/Gold interface. Thus at a critical value of 6 nm, the AlGaN band energy was maximum and AlGaN/Gold interface potential was minimum. The gate potential as a function of varying TGA thickness is depicted in Fig. 2. It was observed that an increase or decrease in the TGA thickness from a critical TGA thickness value leads to a small positive rise in the interface potential.

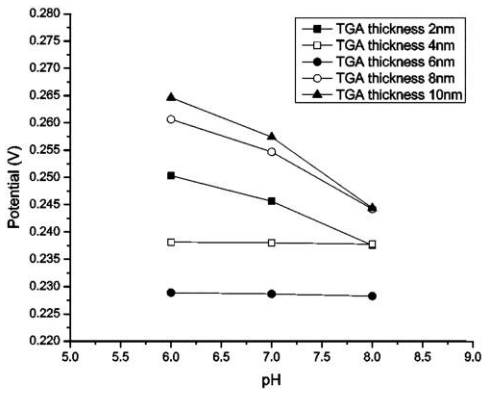

Fig. 2: Interface Potential at AlGaN surface as a function of pH, for various TGA thicknesses

C. Sensing of c-erbB-2 in saliva: The best sensing parameters were considered for the AlGaN/GaN HEMT for optimized sensing of c-erbB-2. The variation in current was simulated for three different concentrations of c-erbB-2 – 0.2 μg/ml, 2 μg/ml and 20 μg/ml, for the cases with saliva at clinically relevant pH 7 and 7.5, as depicted in Figure 3. A significant difference in current of the order of 0.5 μA at pH 7, and of the order of 100 μA at pH 7.5, was obtained which indicated the c-erbB-2 concentration related high sensitivity of device.

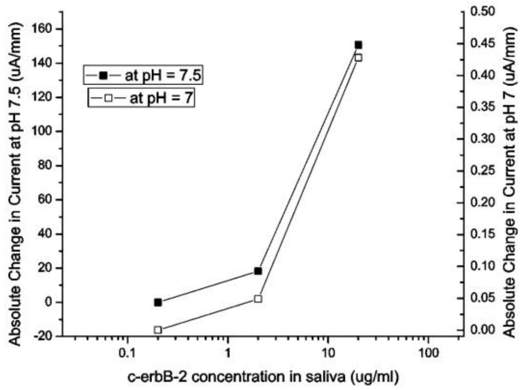

Fig. 3: Change in current in μA/mm as a function of c-erbB-2 concentration at pH 7 and 7.5

Conclusion

Sensing operation of biosensor based on AlGaN/GaN HEMT was studied for breast cancer detection by modeling the constituent materials of saliva and bio-functionalized layers. The effect of interface charge densities, TGA concentration and c-erbB-2 was simulated. The interface charge densities enhanced the sensitivity of current with reference to the gate potential generated by electrolyte. The gate potential of the device exhibited a critical TGA thickness dependent sensitivity with respect to change in its concentration. At pH 7.5, the device exhibited high current sensitivity of the order of 100 μA/mm for 20 μg/ml change in c-erbB-2 concentration in saliva.

Acknowledgment

The authors are indebted to Dr. Chandra Shekhar, director CEERI, Pilani and Dr. C. Dhanvantri, GL, ODG, CEERI, Pilani for their support and encouragement.

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