Performance Analysis of III-Nitride Materials based Biosensors for Detection of Albumin Protein

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Abstract

In this work, AlGaN metal-oxide-semiconductor high-electron-mobility transistor (MOS-HEMT) based biosensor has been presented for detecting the albumin protein. The simulation results of the sensitivity parameters used to detect albumin protein such as drain current, transconductance, output conductance, gate-to-drain capacitance, and sensitivity have been obtained with atlas-technology computer aided design (Atlas-TCAD). The AlGaN/GaN MOS-HEMT device is optimized, in require to improve the biosensor sensitivity. The sensitivity obtained is 55.81%.

Keywords: AlGaN; MOS-HEMT; biosensors; permittivity; albumin.

AlGaN MOS-HEMTs based Biosensors Structure

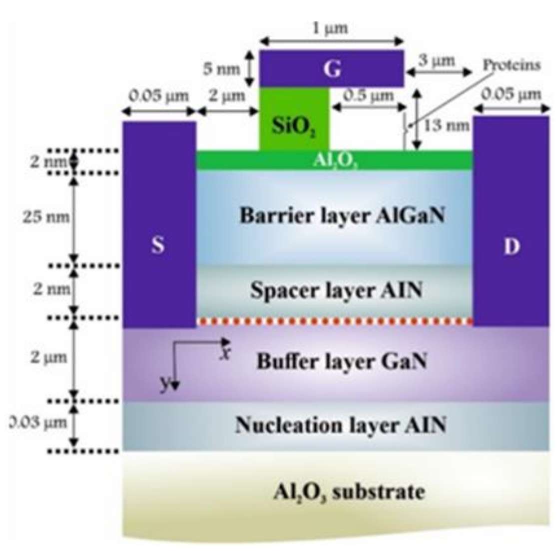

Fig. 1 Cross-section schematic of AlGaN/GaN MOS-HEMT based biosensors.

Results

Fig.2 shows the output characteristics of AlGaN/GaN MOS-HEMT device with albumin protein at V_{gs} = 0 V. The change is plotted against the air-filled cavity region of biosensors and it can be clearly seen that there is a change in drain current of 0.75 A/mm at V_{ds}=12 V. There is an increase in the charge density in the channel region when the protein is introduced in the cavity region, which leads to decreasing the drain current.

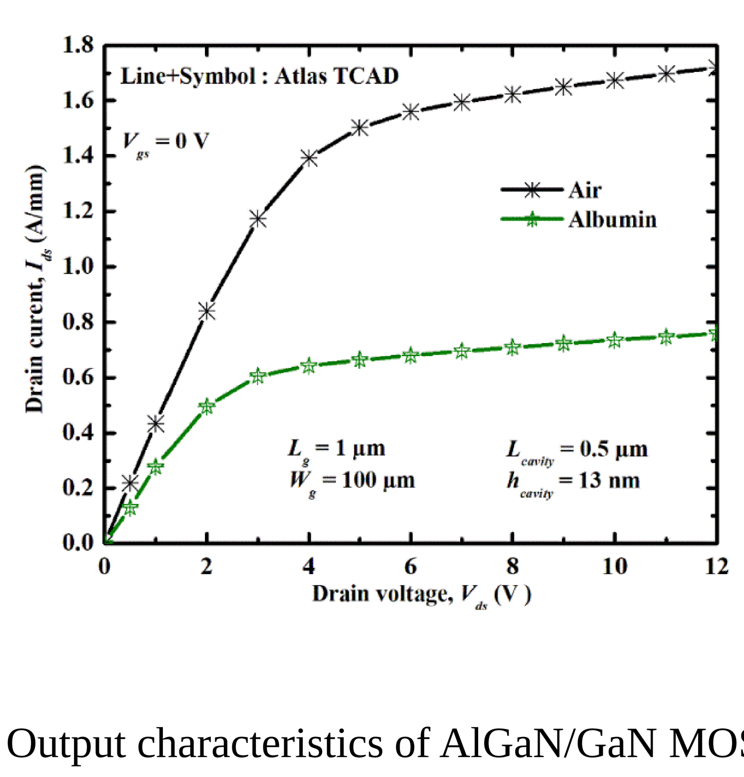

Fig. 2 Output characteristics of AlGaN/GaN MOS-HEMT device with albumin protein at V_{gs} = 0 V.

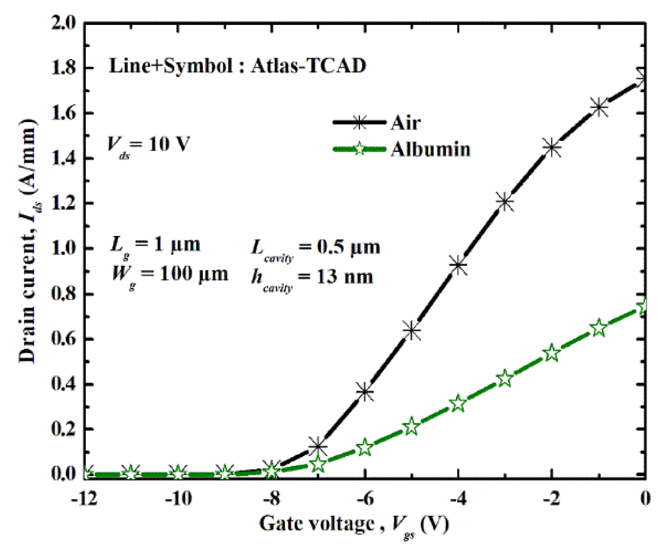

Fig. 3 Transfer characteristics of AlGaN/GaN MOS-HEMT device with albumin protein at V_{ds} = 10 V.

Fig. 3 shows a transfer characteristic with albumin protein of the proposed model of AlGaN/GaN MOSHEMT based biosensors simulated at V_{ds} = 10 V. Furthermore, the drain current is decreased with increasing the permittivity and the variation in drain current has been observed for Albumin protein ΔI = 0.97 V.

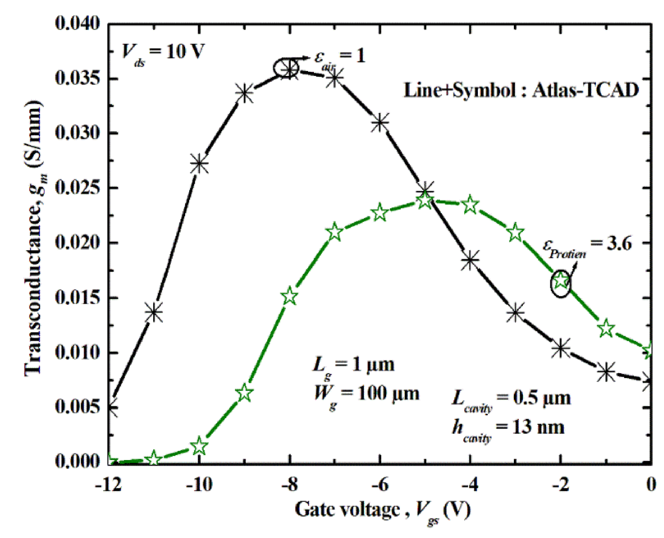

Fig. 4 Transconductance characteristics of AlGaN/GaN MOS-HEMT device with albumin protein..

The transconductance is an important parameter for different device applications. The electrical perusal of AlGaN/GaN MOS-HEMT based biosensors are usually performed by monitoring the variation of the drain current [1], therefore high transconductance is usually required. In AlGaN/GaN MOS-HEMT device, it is often necessary to increase the biosensing area to make current variations easily detectable. Fig. 4 shows the transconductance characteristics of AlGaN/GaN MOS-HEMT device with albumin protein permittivity. The maximum transconductance is 0.0361 S/mm without proteins and 0.0235 S/mm for albumin.

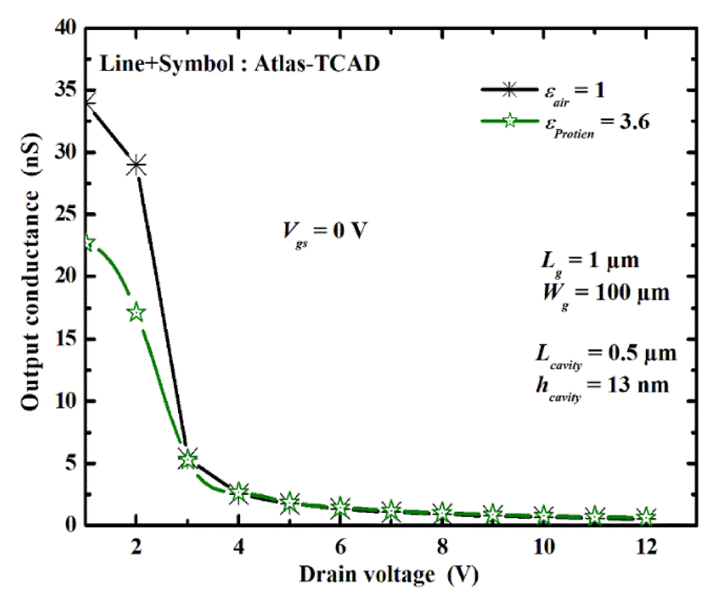

Fig. 5 Output conductance of AlGaN/GaN MOS-HEMT device with albumin protein at V_{gs} = 0 V.

Fig. 5 shows the output conductance (g_d) of AlGaN/GaN MOS-HEMT device for albumin protein. From the output characteristics, there is a high increase in drain current, and a variation in output conductance is observed with the addition of the permittivity of the albumin protein in the cavity region of biosensors. Diminution in (g_d) show the augmentation of resistance of the device due to capacitive coupling of higher negative charge in the cavity. At the same time, the gate-to-drain capacitance of AlGaN/GaN MOS-HEMT device decreases with the increase in drain voltage for albumin protein permittivity, as observed in Fig. 6.

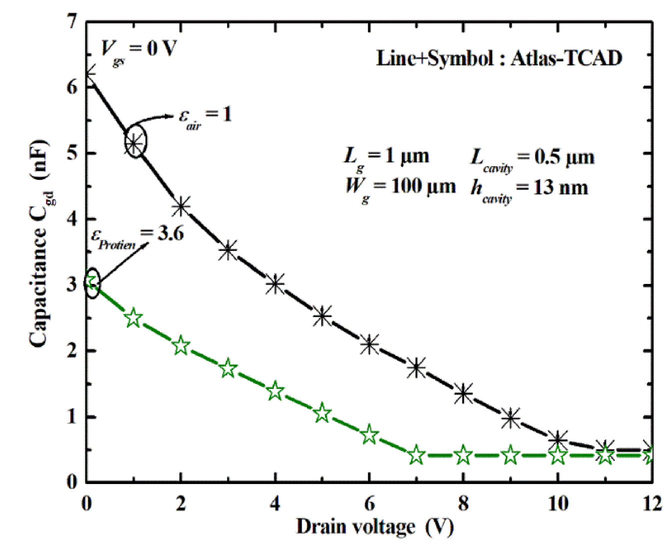

Fig. 6 Comparison of gate-to-drain capacitance of AlGaN/GaN MOS-HEMT device extracted by Atlas-TCAD for albumin protein.

In Fig. 6 the capacitance is varying gradually with an increase in drain voltage, when the device becomes saturated, so that the drain voltage can affect the charge in the channel [2].

The sensitivity parameter $S_{I_{off}}$ of the device at $V_{gs} = 0\ V$ can be defined by threshold voltage and drain current. sensitivity parameter for drain current is defined as follows [3]

$$S_{I_{off}} = \frac{I_{off}\,(With\ Biomolecule\ Species)}{I_{off}\,(Without\ Biomolecule\ Species)} \quad \text{at } V_{gs} = 0\ V$$

the sensitivity obtained of drain current S_{Ids} of Albumin protein that permittivity is considered to be $\varepsilon_{proteins}$ = 3.6 is 55.81%, whereas ε_{air}= 1 is the reference permittivity.

Table 1. Value and electrical parameters of AlGaN/GaN MOS-HEMT based biosensors with albumin protein permittivity.

Parameters	Permittivity ε	
	ε_{air} = 1	$\varepsilon_{protein}$ = 3.6
I_{ds} (A/mm)	1.72	0.75
g_m (S/mm)	0.036	0.0237
C_{gd} (nF)	6.35	3.16
g_d (nS)	34.37	20.05
Sensitivity S_{Ioff} (%)	---	55.81

Conclusion

In this work, the performance analysis of electrical properties of AlGaN MOS-HEMTs based biosensors with different proteins has been reported. A new structure to detect proteins is proposed and designed. Besides, the simulation results indicated that the sensitivity value of biosensors could increase with increase in the protein permittivity, the biosensor has higher sensitivity of 82.15% for zein protein compared to other proteins which are (65.11, 55.8, 52.32) % for casein, albumin and dry protein, respectively. Moreover, our findings demonstrate the use of AlGaN MOS-HEMTs based biosensors for the low operating power and rapid detection of specific proteins in foods for good human health.

Reference

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Conflicts of Interest

The authors declare no conflicts of interest.