

AlGa_{0.4}Ga_{0.6}N Field Effect Transistors for Protein Detection in Physiological Buffer

Biological sensors have a wide range of applications, including the detection of weapons for massive destruction, the clinical diagnosing of diseases, and the development of new medicine, etc. Label-free detection of biomolecules based on electrical field devices has been demonstrated at a sensitivity down to fM level at a low ion concentration buffer, but detection at high ion concentrations is challenging because of the electrical screening effect and current drift caused by ion diffusion. In this research, we demonstrate the feasibility of an AlGa_{0.4}Ga_{0.6}N heterostructure field effect transistor (HFET) for the detection of proteins in a physiological buffer.

Surface Oxidization of AlGa_{0.4}Ga_{0.6}N

To compare the impacts of oxidization on the AlGa_{0.4}Ga_{0.6}N surface, different methods, including wet chemicals (WC) treatment, oxygen plasma treatment by inductively coupled plasma (ICP), oxygen plasma treatment by reactive ion etch plasma (RIE) treatment and remote plasma (RP) treatment, have been investigated. A 0.5 μm thick Al_{0.4}Ga_{0.6}N layer on a sapphire wafer is used to optimize the oxidation process. To oxidize wet chemicals, a sample was rinsed in an H₂SO₄:H₂O₂

mixture for 20 min. For oxygen ICP treatment, the chamber pressure was set to 20 mTorr, and high density plasma with 0 eV ion energy was used for treatment for 30 sec. For oxygen RIE plasma treatment, the chamber pressure was set to 5 mTorr, the ion energy was 10 eV, and the duration was 5 minutes. For remote plasma (RP) treatment, the duration was 24 hours.

After the treatments, the surface oxides were characterized by X-ray photoelectron spectroscopy (XPS). O 1s XPS spectra were shown in Figure 1. The oxygen intensities decomposed into O-Al and O-Ga bonds while O-Al bonds have higher binding energy than O-Ga bonds. The O-Al and O-Ga ratios show that the RP introduces essentially no changes on the O-Al and O-Ga ratios, indicating that RP oxidation is not very effective compared with other methods after 24 hrs of treatment.

APTES Deposition

The samples were deposited with 3-aminopropyltriethoxysilane (3-APTES) to modify the surface with amine groups. After boiling in DI water, the samples were then rinsed in 2% 3-APTES in acetone for 30 min. The silanized samples were washed in acetone, propanol, dried with a nitrogen gun and then baked at 120 °C for 5 min. After deposition, XPS and SIMS measurements were used to characterize the APTES layer.

SIMS analysis was performed on a PHI TRIFT-III TOF SIMS with a background pressure of 10⁻⁹ torr. An oxidized sample deposited with APTES and an oxidized sample without APTES was measured.

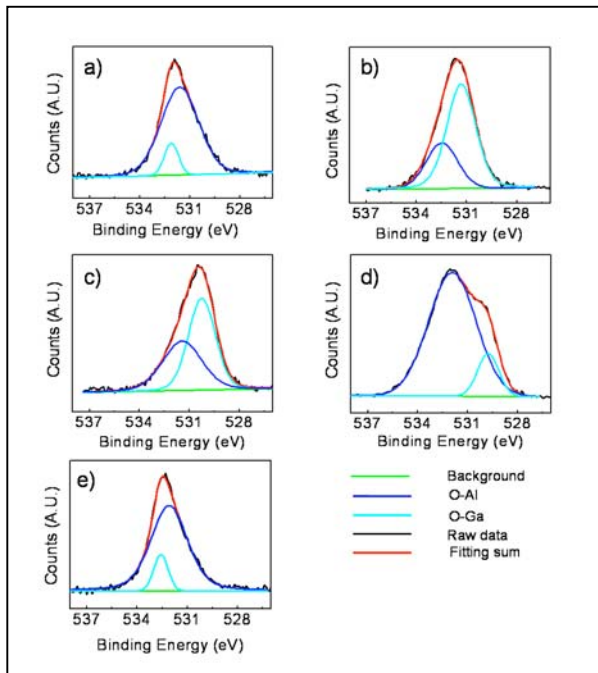


Figure 1. XPS O 1s peaks of differently oxidized AlGa_{0.4}Ga_{0.6}N surfaces.

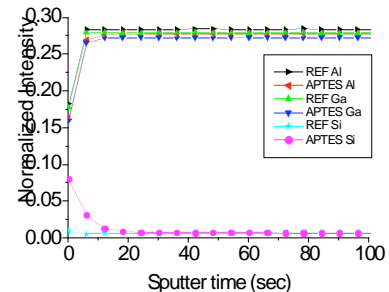


Figure 2. SIMS results on AlGa_{0.4}Ga_{0.6}N surface with and without surface functionalization.

Figure 2 shows the SIMS data from the two samples.

Ga and Al atoms were collected to confirm the validity of the measurement, and Si atoms were collected as the indicator of the presence of APTES. As shown in Figure 2, the number of Ga and Al atoms collected was similar between the two samples, while the number of Si atoms was different. A sharp decrease of Si atom intensity was observed for the APTES treated sample. A clear NH_2^- peak was also observed in the N1s XPS spectra, indicating that the silane chemistry is assembled on the AlGaN surface.

For biotinylation, Sulfo-NHS-biotin (Pierce Biotechnology, Rockford, IL) was dissolved in DI water at a concentration of 1 mg/ml. The solution was then dropped to the AlGaN surface with APTES and then covered by a glass slide. The samples were placed in a humid chamber to prevent water evaporation at room temperature. The samples were then rinsed in PBS and immersed in Superblock buffer (Pierce Biotechnology, Rockford, IL) to prevent any non-specific binding on the exposed area. The samples were rinsed with PBS to remove unbound streptavidin molecules. Furthermore, we used unbound pockets of streptavidin as receptors to detect biotinylated proteins.

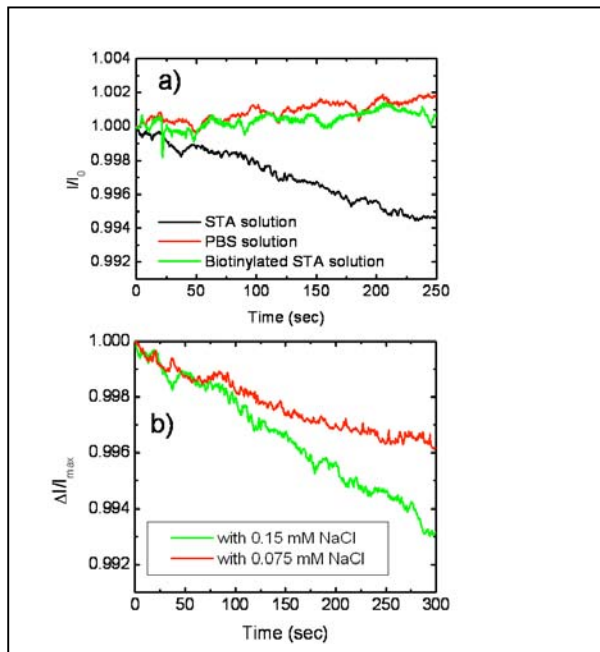


Figure 3. a) Comparison of 1 mg/ml STA in 0.075 mM NaCl and PB and in PB only; b) Comparison of 1 mg/ml STA in 0.075 mM NaCl and PB and in 0.15 mM NaCl and PB.

We have chosen monokine induced by interferon Gamma (MIG) as our analyte.

Electrical Detection

After surface modification, 1 mg/ml STA in PBS buffer and a few control solutions were applied to AlGaN/GaN HFETs with bias. The I-t response was shown in Figure 3. The device exhibited excellent specificity, as it only responded to STA with free packets for specific binding to biotin. Figure 3b shows the device responses because of the Debye length change at different ion concentrations.

For MIG protein detection, as expected, the current increases during the binding process between

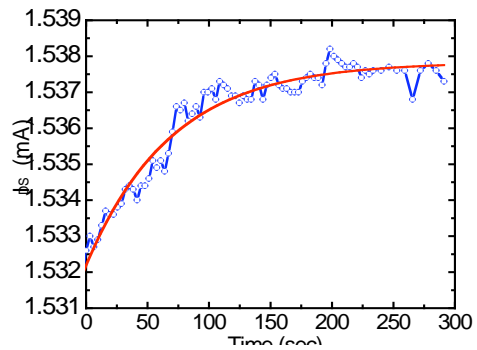


Figure 4. I-t measurement of biotinylated MIG.

STA and biotinylated MIG as MIG proteins are positively charged. Consequently, no current change was detected for un-biotinylated MIG, indicated excellent specificity.

In summary, we have demonstrated that the detection of clinically relevant protein concentration at physiological ion concentration levels is feasible in FET-based biosensors and such devices have great potential in the future development of *in vivo* biosensors.

Publications

1. X. Wen, M. Elias, L. Brillson, S. Lee, and W. Lee, "Surface functionalization of AlGaN for biosensing", 2007 Electronic Materials Conference.
2. S. Gupta, M. Elias, X. Wen, J. Shapiro, L. Brillson, W. Lu, and S. Lee, "AlGaN heterojunction field effect transistors for detection of clinically relevant MIG concentrations at physiological salt concentrations", Biosensors and Bioelectronics (submitted).