AlGaN/GaN FET Sensor for Label Free Detection of DNA Hybridization

Field-effect-based sensors have been demonstrated for label free detection of biomolecules at very low concentrations. Compared with other materials, the AlGaN/GaN heterojunction field effect transistor (HFET) is of great interest because of its high sheet carrier concentration and good chemical stability in physiological buffers. In this work, we have used AlGaN/GaN HFET sensors as a platform to study the dynamic process of DNA hybridization.

Surface Functionalization

The processes of immobilization and hybridization of ssDNA on Au surfaces were first studied by fluorescent imaging and AFM measurements before they were transferred to AlGaN/GaN surfaces. The study was performed on Si substrates with Au patterns. 12 mer desalted oligonucleotides (Sigma-Aldrich) were used in this study. Table 1 shows the sequences of probe and target ssDNAs. There are two sets of each specific sequence, which are with and without fluorescent labeling. p1 and t2 are matched ssDNA sequences, while t1 is a mismatched sequence to p1 for control study. A TE buffer with pH 8.0 was used in this experiment.

The fluorescent images are shown in Figure 1. The left side of each picture shows the fluorescent images with a sampling bar. The right side shows the fluorescent intensities vs position across the sampling bar. The fluorescent images were taken in an aqueous condition. These images show that the fluorescence intensities changed upon the attachment of labeled ssDNA, indicating that surface functionalization and the surface coverage is fine.

probe	p1	5'-CCT AAT AAC AAT 3'-C_2-thiol
probe	fp1	Cy5-5'-CCT AAT AAC AAT 3'-C_2-thiol
target	t1	5'-AAA AAA AAA AAA-3'
target	ft1	Cy3-5'-AAA AAA AAA AAA-3'
target	t2	5'-ATT GTT ATT AGG -3'
target	ft2	Cy3-5'-ATT GTT ATT AGG -3'

The surface morphology of self-assembly monolayers (SAMs) is characterized by AFM. The AFM images of Au surfaces during the immobilization and hybridization process are shown in Figure 2.

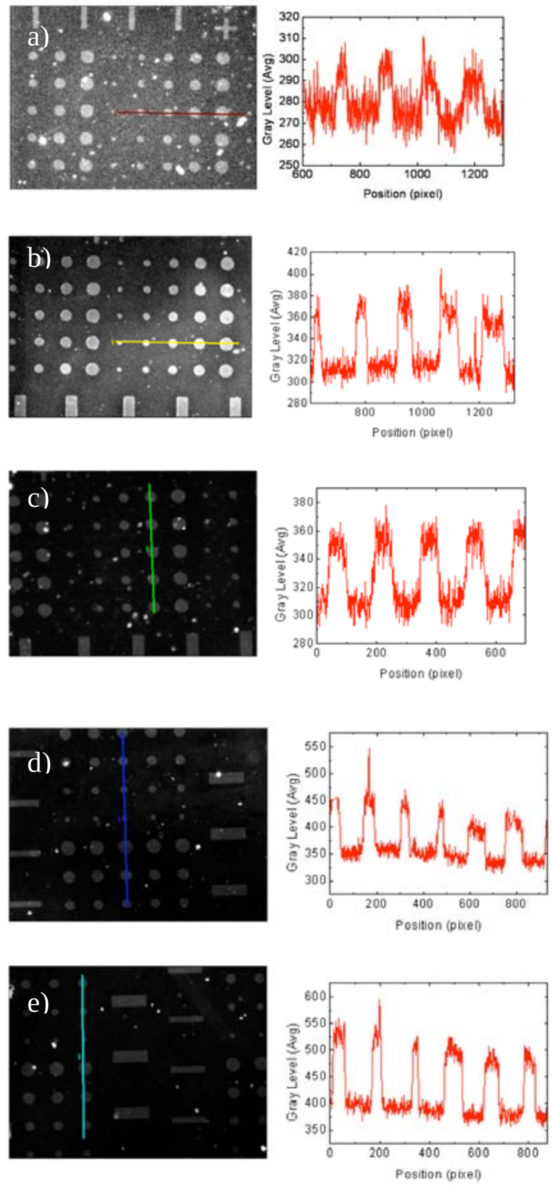

Figure 1. The fluorescent images of Si substrates with Au patterns in the process of ssDNA immobilization and hybridization. (a) background image of Cy5 excitation wavelength; (b) image after probe ssDNAs immobilization; (c) image of Cy3 excitation wavelength with probe ssDNA immobilized; (d) image after treated with mismatched ssDNA solution; (e) image after treated with matched ssDNA solution.

The grain sizes in Figure 2 confirmed the immobilization and hybridization of the ssDNA molecules. In Figure 2 (a), there are no circular grains

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on the Au surface, and the feature pattern sizes are the smallest, which is the initial condition for ssDNA molecules to attach. Figure 2 (b) shows the Au surface morphology after the sample had been rinsed in 1mM probe ssDNA solution for 12 hours. Circular grains appeared all over the Au surface because of the attachment of the probe ssDNAs. It shows that immobilized ssDNAs on the Au surface exist as clusters. Figure 2 (c) shows that the circular grain sizes were increased further by the attachment of target ssDNA molecules. The surface roughness of the Au surfaces did not change significantly in the three cases, indicating that the uniformity of SAM is good.

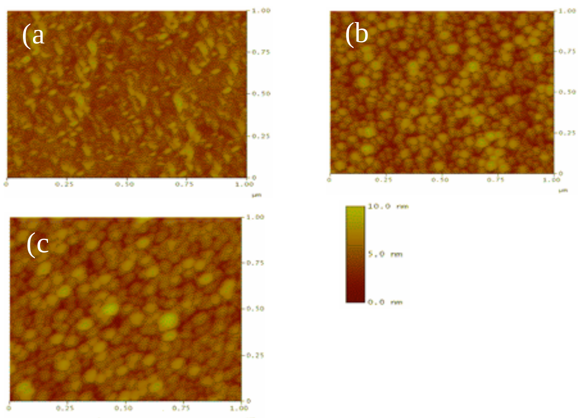

Figure 2. AFM images of Au surfaces (a) after Ti/Au deposition, with a surface roughness is 0.989 nm; (b) after probe ssDNA immobilization, with a surface roughness is 1.265 nm; and (c) after hybridization with matched target ssDNAs with a roughness of 1.172 nm.

Electrical Detection

After the surface modification and immobilization/ hybridization processes were developed on the Si surfaces, the process was transferred to AlGaN/GaN HFETs for electrical detection. The device was then biased at 0.5 V, and the current was monitored by a semiconductor parameter analyzer. Comparison measurements were performed by applying 1mM t1 solution and t2 solution to two different devices, respectively.

Figure 3 (a) shows the current versus time plot during the hybridization process with matched ssDNA target. The hybridization was not observed until around 150 sec after the target ssDNA solution was applied. As shown in Figure 3(a), in the first few tens of seconds, the decrease of current is sharp, and most of the current change happened in this period. In this time range, there were enough target ssDNA molecules to hybridize with the surface probes, which indicates the current change rate is dominated by the ssDNA hybridization process. Figure 3 (b) shows the control measurement with the mismatched target ssDNA solution applied. There was no appreciable current change observed, indicating that the hybridization and physical adsorption of target ssDNA molecules to the modified Au surface is minimal.

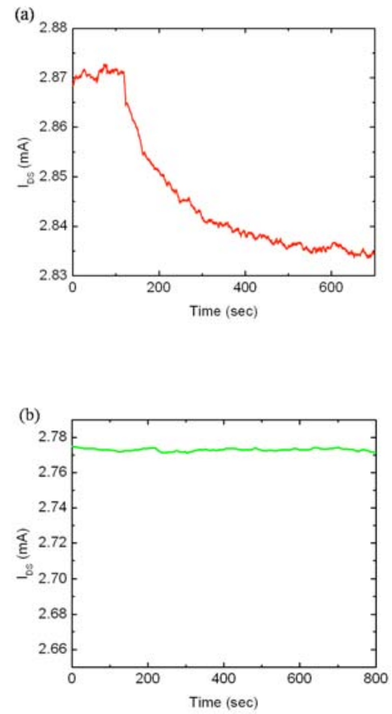

Figure 3. Time-dependent responses of AlGaN/GaN HFETs with probe ssDNAs on Au-modified gate to (a) matched and (b) mismatched ssDNA solution.

The dynamic response suggests that in the first few tens of seconds, the DNA hybridization process was dominated by the conjugation between the matched ssDNA sequences. After that, the hybridization process was dominated by the mass transfer process and saturation of the immobilized probe ssDNA molecules.

Publications

1. Xuejin Wen Shengnian Wang, Ly James Lee, and Wu Lu, “AlGaN/GaN Heterostructure Field Transistors for DNA Hybridization Detection”, 2007.
2. Xuejin Wen, Shengnian Wang, Ly James Lee, and Wu Lu, “AlGaN/GaN Heterostructure Field Transistor for Label-Free Detection of DNA Hybridization”, IEEE Sensors Journal (submitted).

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