DNA hybridization sensor based on AlGaN/GaN HEMT

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1 Introduction

Semiconductor based biosensors for detecting DNA sequences is an area of intense research due to its applications in biotechnology, molecular biology and the pharmaceutical industry. Several different methods including optical [1, 2], changes in mass [3], electrochemical detection [4, 5] have been developed for this purpose. Most of these methods include using a labeling agent [6] or are expensive, time consuming, tedious and destructive. Semiconductor-based biosensors are better than the above mentioned procedures since they are label free, nondestructive and fast [7-10].

AlGaN/GaN heterostructure based field effect transistors are ideal candidates for such purposes since they have a high electron sheet concentration induced by spontaneous and piezoelectric polarization of the strained AlGaN and the GaN layer. In this work, we use a 22 base pair best representing Salmonella DNA to show the functioning of the device as a DNA hybridization sensor. Two different DNA concentrations are used to verify whether a higher DNA concentration leads to a higher change in drain current. The application of photodefiable PDMS as a stable encapsulant is also verified.

2 Experiment

2.1 AlGaN/GaN heterostructure

The heterostructure consists of a thin AlN layer, 2.7 μm GaN buffer, 20 nm AlGaN and a 2 nm GaN cap layer. The wafer is purchased from SVT Associates. The purpose of using the GaN cap layer is to reduce the surface states and in improving the ohmic source and drain contacts without having any adverse effects on the Schottky contact. The epilayers are grown on top of sapphire. The 2DEG mobility is greater than 1300 cm²/v-s at room temperature.

2.2 DNA Sensor fabrication

The HEMT was fabricated on the wafer using the following procedures; The GaN wafer is initially cleaned in organic solvents and acid to remove contaminants. Device isolation is achieved using NF3 plasma. This procedure al-
so maintains device planarity. Ni is used as a sacrificial mask during this process. The ohmic contacts consist of Ti/Al/Ni patterned using lithography and liftoff. These contacts are annealed at 750 °C under flowing N2. A very thin layer of chromium and gold are patterned on top of the annealed ohmic contacts. This metallization scheme is followed to ensure low contact resistance ohmic contacts which also give mechanically strong gold wire bonds. The Schottky contacts consist of Ni/Au. After making the gold wire bonding to the ohmic contacts, photodefimable polydimethylsiloxane (PDMS) was spin coated on the device. This spin coated photodefimable PDMS was then patterned by lithographic techniques so that we have a 20μm thick encapsulation layer covering the device except for the gate area of each device.

The DNA immobilization on the gold surface is performed using the following procedure: The exposed gold-coated gate area is first cleaned with piranha solution, followed by rinsing in DI water. The surface is then treated with 50 μl of thiolated probes of 4 μM and 1 μM of 5'-SH-(CH2)6-CGCTTGAAGAGGTCAATGGCCA- 3' in the immobilization buffer for 6 hours. The surface is then washed with immobilization buffer and then treated with 50 μl of 1 mM MCH in Abs. ethanol for 90 min.

The I-V characteristics of the device are then measured after these procedures. The DNA immobilized surface is then exposed to the target SS-DNA in the hybridization buffer solution. The I-V characteristics of the device is measured after waiting for a period of about 15 min. The change in the I-V characteristics of the device during these processes is measured. The device is also checked for usability which confirms the stability of the device and the encapsulation. XPS is used to confirm the probe immobilization.

Figure 1 shows the PDMS encapsulated device with the gate contact open for DNA immobilization. PDMS was found to have good adhesion to AlGaN/GaN wafer as well as to the ohmic contact metallization. Figure 2 and 3 show the change in the drain current during the probe immobilization and target hybridization. Figure 2 shows the change in the drain current with a 4 μM DNA concentration. The drain current decreases as a function of time during the probe immobilization and stabilises after 6 hours. After the immobilized DNA is exposed to the target DNA, there is a decrease in the drain current and the current level stabilises after 15 minutes. A similar trend is observed when DNA concentration of 1 μM is used. The decrease in the drain current is larger with 4 μM as compared to 1 μM. Figure 4 shows a high resolution XPS scan over the sulphur S2p peak with a wide peak with a peak binding energy of about 162.1 eV, which confirms sulphur- gold bonding [11]. The wide S2p peak indicates multiplicity of bonding states like S-H, S-C & S-P notably S-H.
4 Conclusion

We have detected DNA hybridization using an Al-GaN/GaN high electron mobility transistor. Two different DNA concentrations were used and there was a larger decrease in current with the higher concentration. Photodefinedable PDMS was also found to provide stable encapsulation.

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