The influence of electrode on sensitivity of pH sensors fabricated on AlGaN/GaN heterostructures

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ABSTRACT

In this paper, we report on metallization stack as an ohmic contact to gateless AlGaN/GaN high electron mobility transistors (HEMTs). As compared with Ion-Selective Field Effect Transistor (ISFET) based on Silicon, AlGaN/GaN HEMT has several attractive points for various chemical and biological sensor applications. One of the unique features in AlGaN/GaN, which is a high-density Two Dimensional Electron Gas (2DEG), is known to allow highly sensitive detection of surface phenomenon. Many researchers have elucidated the mechanism and improved sensitivity with perspective of 2DEG. However, there are no researches that explain why Ti/Al/Ti/Au stack is used as an ohmic contact in pH sensors based on AlGaN/GaN HEMTs. We focused on the relationship between ohmic materials on AlGaN/GaN HEMT and sensitivity of pH sensors.

Keywords: pH sensor, Sensitivity, Surface Potential Charge, Ohmic contacts, AlGaN/GaN HEMT

1 INTRODUCTION

Measurement of pH plays an important role in many fields such as pharmacy, chemistry, and biology. Therefore, pH sensor devices are required to compatible with electronic devices and to bear harsh environments. Most of the pH sensors is consisted of a type of glass electrodes. The main issues on improvement of pH sensor are miniaturization, stability, and sensitivity so far. Among candidates for pH sensors, the Si based Ion-Selective Field Effect Transistor (ISFET) has been studied for many years. However, Si-ISFET still has a limitation on operating at high-temperature since maximum operation temperature of Si-ISFET is around $60^{o}C$ [1]. In contrast, GaN, a wide bandgap semiconductor, is chemically stable, non-toxic and thermally stable. The GaN has a high electron mobility, a wide band gap energy (3.4 eV) and a large sheet carrier concentration. Especially, AlGaN/GaN HEMT has been widely used in sensing technology due to sensitive analysis resulting from characteristics of a Two Dimension Electron Gas (2DEG) structure. The density of 2DEG is modulated by the surface potential charge of the channel gate on AlGaN/GaN HEMT. Since Steinhoff published the first report of a GaN-based pH sensor with an open-gate structure [2], many researchers have reported the sensing mechanism and various way to imporve pH sensitivity. However, research on Ti/Al/Ti/Au ohmic stack consisted of drain and source in devices has not yet been done. In this work, we evaluated relationship between specific contact resistance and sensitivity of pH sensor by changing the ohmic contact metallization consisted of source and drain.

2 EXPERIMENT DETAILS

The AlGaN/GaN heterostructure in this experiment was fabricated for analysis of electrical characteristics and measurement of pH sensitivity. The AlGaN/GaN structure was a commercial wafer provided by NTT-AT and grown on a 6-inch Si(111) wafer by MOCVD. The structure consisted of a ~4-um C-doped GaN buffer layer, a C-doped i-GaN layer, a ~300-nm i-GaN layer and a ~20-nm i-$Al_{0.25}Ga_{0.75}N$ layer with a ~2-nm n-GaN layer. The drain and source electrodes were formed by deposition of ohmic multilayers. Being multilayers of Ti/Al/Ti/Au (50/200/40/40 nm), Ti/Al/Ni/Au (50/200/40/40 nm), and Ti/Au (50/40 nm). Annealing process at $850^{O}C$ for 30s by Rapid Thermal Annealing (RTA) system and conventional lift-off process as shown in Figure 1.

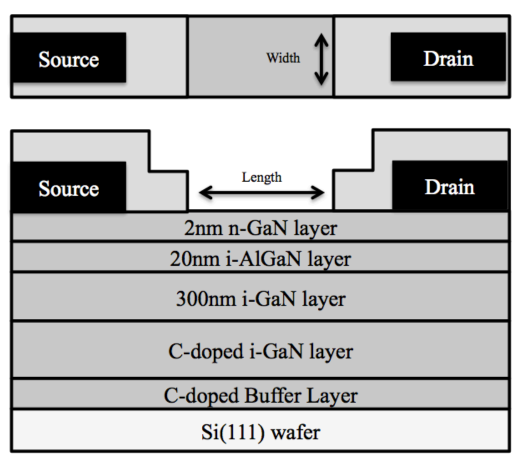

Figure 1. The cross section of a pH sensor on AlGaN/GaN HEMT structures

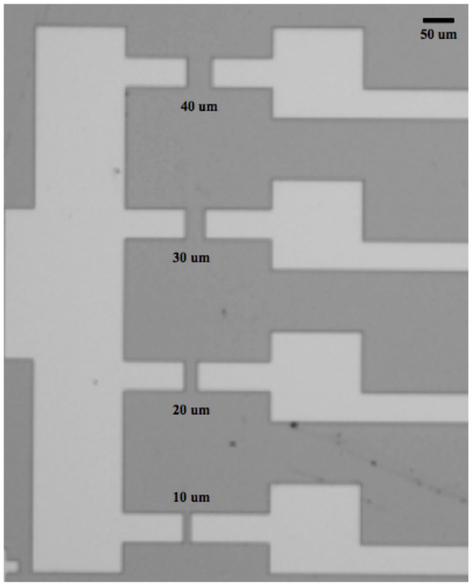

Figure 2. Sensor Device SEM images of open-gate

The device was covered with 300-nm-thick SiO_2 passivation using PECVD to prevent chemical reaction except at the open-gate region. The open-gate region was fabricated through photolithography and wet etching processes[3]. The 50×50 um^2 region of ohmic contacts were separated with gaps of 10, 20, 30, and 40 um. Each seperated regions took a role of the source and the drain part in AlGaN/GaN HEMTs. It means that the exposed open-gate area were 10×50 um^2, 20×50 um^2, 30×50 um^2, and 40×50 um^2. Figure 2. shows the scanning electron microscopy (SEM) image.

When starting the pH measuremet, we used pH 4, pH 10, and pH 7 buffer solution to calibrate the electrode with LE438 Mettler pH meters and DC suppler. All the measurements were processed at room temperature of 25 ^{O}C. Calibration process were consisted of titration using HNO_3, KOH, and de-ionized water (DI water). For the fast measurement of pH, we dropped 1 ~ 2 pH solutions on the open gate area like Figure 3. Also, Figure 4. shows the measurement system used to calculate more correct sensitivity on the pH sensor.

Figure 3. conceptual scheme to measure sensing

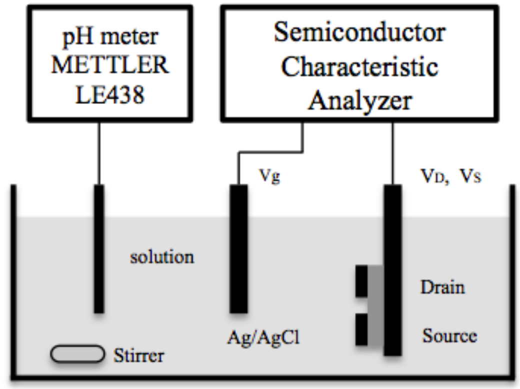

Figure 4. The measurement system of the pH sensor

We measured electrical properties, these are 2DEG and Ohmic contact characteristic, of pH sensors. At first, we assumed the open-gate HEMTs as a resistors. Through the features of 2DEG, we can find the relationship between surface potential charge and 2DEG characteristics. The absoption of OH^- affected the surface potential charge and the sheet concentration on the AlGaN/GaN HEMTs.

Next, we assumed total resistance of pH sensor means adding 2DEG and Ohmic contact resistances. The I-V characteristic was measured by four-probe method. All datas were measured at room temperature of 25 ^{O}C.

3 RESULTS AND DISCUSSION

These open-gate HEMT structure can be regarded as a resistor, linked with source, drain, and 2DEG parts. Simply, source and drain are regarded as ohmic contact, which can be calculated using I-V curve. The following equation is about 2DEG characterisitics. ρ is the specific contact resistance of 2DEG. A, section area of current, can be calculated from multiplication of the width of HEMT (W) and the depth of 2DEG (d_i) formed with AlGaN/GaN interface. L is the length between drain and source. N_S is the sheet concentration of 2DEG[4].

$$R_{2DEG} = \rho\frac{L}{A} = \frac{1}{qu_n(N_S/d_i)}\frac{L}{A} = \frac{1}{qu_n(N_S/d_i)}\frac{L}{Wd_i} \tag{1}$$

$$= \frac{1}{qu_n(N_s/d_i)}\frac{L}{Wd_i} = \frac{L}{qu_nN_SW}$$

The adsorption of OH^- on the AlGaN/GaN surface affects the surface potential charge (V) and the sheet concnetration (N_S)[6]. Figure 5. is one of the expected results with the measurement condition of 20 × 50 um^2 gate section. We measured the slope of I-V curve and calculated each component of the equation. The slope of I-V curve decreased when pH was increased.

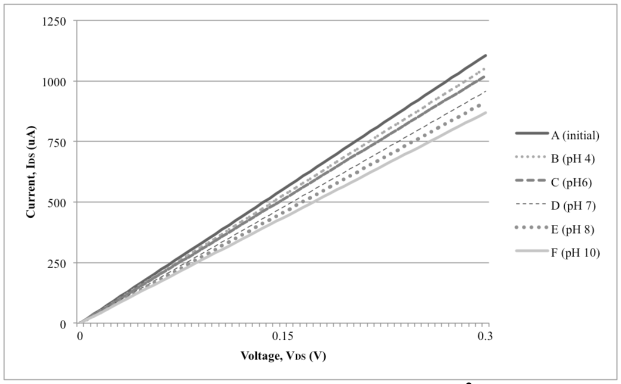

Figure 5. The slope of I-V curve for 20×50 um^2 open-gate

The change of source and drain materials in AlGaN/GaN HEMTs causes different total device resistance and sensitivity. We can improve the sensitivity of pH sensor from decreasing total resistance to induce efficiency increase.

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