An investigation into signal stability during measurement of AlGaN/GaN transistor-based chemical sensors

F.L.M. Khir, A. Lyons, M. Myers, M.V. Baker, B.D. Nener, and G. Parish

Abstract- AlGaN/GaN transistor-based sensors are highly sensitive to changes in charge at the semiconductor-solution interface. Significant care controlling the measurement conditions is required for stable and robust sensor operation. In this study various aspects of measurement protocol were investigated in order to minimise the drift in sensor output during measurements. The most significant factors were found to be the use of buffered ionic solutions and the use of a Faraday cage.

Index Terms- AlGaN/GaN, chemical sensor, drift, noise

I. INTRODUCTION

AlGaN/GaN-based high electron mobility transistors (HEMTs) are well known for their physical and chemical characteristics, in particular their fast response and robust operation in extreme environments. These characteristics combined with a high surface sensitivity to changes in charge have made these devices attractive for chemical and biological sensing [1-3]. However, as with silicon-based sensors, AlGaN/GaN devices exhibit significant sensor drift characteristics during measurements in chemical solutions, which must be understood and mitigated for reliable operation [4].

Sensor drift investigations of silicon-based devices have involved device modelling and development of compensation techniques [5-7]. This may be due to the necessity for the gate dielectric to be operated under biased conditions [6,8], which restricts aqueous measurements of silicon-based device characteristics over a long period of time. Conversely, the robustness and electrical characteristics of AlGaN/GaN based sensors renders them potentially suitable for long term measurements under non-biased conditions. Here we report an investigation based on different experimental set-ups in an effort to minimise sensor drift, that is, the shift in sensor output potential seen over time when all other conditions are kept constant.

For this study, the active region of the sensor was not passivated/ treated, with the assumption that a native oxide exists on the surface [9]. A number of measurement set-ups were investigated, with the aim to minimise the effects of variations during measurements. These include, for an example, the use of a battery pack, anti-static mat and Faraday cage.

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II. SENSOR FABRICATION

Metal-organic chemical vapour deposition (MOCVD) was used to grow the AlGaN/GaN transistor-like heterostructure that would later serve as a sensor for this study. The AlGaN layer consisted of 23% aluminium (Al), was 12 nm thick and had a 2 nm GaN cap. The sample was etched using a Plasma100 at ICP/RIE power of 75 W/150 W for isolation of the device structures. This was followed by thermal deposition of electrical contacts (Al (20 nm)/Cr (50 nm)/Au (300nm)). The sensor was fabricated as a Kelvin probe structure (Fig. 1), precluding the need for an external reference electrode.

Fig. 1. Plan view of AlGaN/GaN HEMTs-based chemical sensor.

For protection during aqueous measurements the device was coated with silicone RTV 3140 (Dow Corning) except on the active area.

III. EXPERIMENT

To obtain a baseline for the investigation into the measurement set-up, an experiment was conducted where the sensor was left in air (see Fig. 2). For all other experiments, the sensor was left in the air for 10 minutes prior to immersion in solution. Two types of solution were used: de-ionised (DI) water and 0.1 M potassium dihydrogen phosphate (KH_2PO_4).

Firstly, repeated experiments with DI water as a test solution (made with the aid of an anti-static mat) were undertaken to observe the behaviour of the sensor response in the absence of solute ions. All the experimental apparatus was

placed on the anti-static mat; where it would be electrically grounded throughout the experiments. The characteristics for the sensor potential as a function of time are shown in Fig. 2. The sensor drift for the measurements in DI water can be seen as a significant upward shift in sensor potential over time. In addition the measurements in water demonstrated medium (blue) and low (black) levels of noise, in comparison to negligible noise in air (red).

Fig. 2. Plot of sensor response vs. time for the experimental set-up with anti-static mat. The sensor was immersed in DI water

Subsequently, various experimental setups were compared which included the use of a Faraday cage and the use of a grounded platinum electrode. Furthermore, to minimise the possible effect of variations in power supply, experiments were conducted where the data acquisition system (Datataker DT82 Series 2) was powered by a DC power battery pack instead of mains AC power. Experiments were conducted at a lab bench without artificial lighting and shielded by an open-top box (when not located inside a completely dark Faraday cage) to minimise the effects of light on the device response. Comparisons were also made between experiments undertaken with and without electronic devices nearby (laptops, mobile phone and watch), to monitor for potential impacts during the measurement.

Fig. 3 plots the average sensor drift (calculated by dividing total change in potential by total measurement time) and Fig. 4 the average noise (calculated as the moving average value) in output potential for the two types of solution used and the various experimental configurations. As numerous comparisons can be made within these figures, each comparison will be addressed separately in the discussion below.

Firstly, comparing the data points for DI water with and without electronic technology (“mat + battery” versus “mat + battery + no tech”) indicates that the effect of having electronic devices near the experimental area does not particularly affect sensor performance, with average sensor drift differing by approximately 1 mV.

Even though it would not be practical to use a Faraday cage for *in situ* measurements in most sensor applications,

investigations were performed in a Faraday cage to observe the stability of the response when the set-up is isolated from environmental effects. The completely dark conditions in the Faraday cage could also contribute to the lower observed average sensor drift and noise compared to measurements not conducted in the Faraday cage. Nevertheless, Fig. 3 shows a clear reduction of approximately 50% for the average variation for measurements in the Faraday cage compared to those not in the Faraday cage.

Fig. 3. Plot of average sensor drift vs. DI water and 0.1 M KH_2PO_4 test solutions for various experimental configurations (mat = anti-static mat; battery = DC battery for Datataker; no tech = measurements taken without other electronic devices in the vicinity; cage = measurement inside Faraday cage; electrode = Pt reference electrode).

The average noise is calculated by the difference from a 120 second moving data average. Significant average noise of approximately 3 mV (Fig. 4) was witnessed when the anti-static mat was placed inside the cage. This could be the result of a ground loop occurring between the mat and the cage. Therefore, it was concluded that the mat is not suitable to use in combination with the Faraday cage.

The investigation with and without the battery pack is practically useful given the likelihood of in-situ field analyses in the future. Surprisingly, the average sensor drift for the experiment performed with a battery pack is observed to be ~4mV/hour higher compared to experiments using AC power. This shows that the 50 Hz AC power, which was initially considered as a possible source of noise or drift, is not detrimentally affecting the measurement.

The comparative study between measurement set-ups with and without a grounded reference electrode (Fig. 3) showed that the platinum electrode does not play a role in minimising the variation for the set-up, at least when measured inside the Faraday cage in 0.1 M KH_2PO_4 buffer solution.

Fig. 4. Plot of noise vs. DI water and 0.1 M KH_2PO_4 test solutions. The average noise values were calculated from the moving average of the data (mat = anti-static mat; battery = DC battery for Datataker; no tech = measurements taken without other electronic devices in the vicinity; cage = measurement inside Faraday cage; electrode = Pt reference electrode).

Notably, use of the buffer solution in most cases reduced average sensor drift compared to DI water. This may be the result of the ions interacting with the active area on the sensor surface during measurements. These findings are in agreement with Chaniotakis et al. where the activity of anions can be measured by the interfacial potential [10].

Based on this work, we have seen that optimising the measurement set-up can significantly lower drift and noise in the sensor signal. The average sensor drift over the time intervals seen here (particularly in buffer solution) were near to or lower than seen in study by Liu et al. in which an average drift of 5.8 mV/hour was reported. They proposed that the potential at the gate was altered due to the variability of the thickness of the surface hydrated layer, resulting in an output-drift especially for long term sensor operation [11].

It is critical to understand how the various experimental factors affect the response exhibited by the sensor; not only factors related to the measurement configuration and conditions but also those resulting from reactions at the sensor surface. Further investigations are underway to explore additional factors, such as changing the temperature of the constant current control circuit to monitor the effect of temperature on the chip during the measurement, and modifying aspects of the measurement protocol that influence the sensor surface, such as immersion in fixed ion solutions (e.g. isopropanol) and surface silanisation, to aid in-depth understanding of this response based on the surface characteristic.

IV. CONCLUSIONS

The experimental set-up can significantly affect the sensor drift and noise present during measurements. Based on the measurement configurations and conditions studied here, we found that use of a DC battery instead of AC power and

use of a platinum reference electrode both have minimal effect on performance.

It was also shown that 0.1M KH_2PO_4 buffer solutions reduce the observed sensor drift most significantly, most likely by controlling the ion concentration in the solution compared to the DI water. Finally, the sensor drift is also reduced significantly with the use of Faraday cage as it shields the measurement from external effects such as light and electromagnetic radiation. A notable exception is the detrimental effect when both a Faraday cage and anti-static mat are used.

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