GAS SENSITIVE Al MEMBARANE ON N-TYPE GaN SCHOTTKY DIODE

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Abstract: In this work, we have studied and fabricated a new, simple and small-size N_2 and H_2 sensitive Aluminum (Al) membrane/semiconductor (Al/n-GaN) Schottky diode sensor. Experimental results revealed that, during the hydride or nitride formation process, the time response increased and enhanced with temperatures operation and the forward- currents is increased by the increase of temperature for air, nitrogen and hydrogen. It also demonstrates that the Schottky barrier height is indeed increased with increasing the temperatures for gases. Therefore, the studied device can be used in fabricating a high-performance hydrogen and nitrogen sensitive sensor.

Keywords: Hydrogen sensor, Time response, High temperature, Schottky diode

INTRODUCTION

There has long been an interest in developing solid-state gas sensors [1]. It was recognized early on that the threshold voltage of field effect transistors or the barrier height of Schottky diodes fabricated in Si, SiC, ZnO and the semiconductors was altered upon exposure to hydrogen- containing gases, leading to changes in current in these structures for a given set of biasing conditions [2]. In the intervening period, there has been a steady improvement in the understanding of the hydrogen sensing mechanism [6]. There is particular interest in the development of wide band gap semiconductor gas sensors because of their potential for high temperature operation and the ability to integrate them with power or microwave electrodes or with UV solar-blind detectors and emitters fabricated in the same materials. There have been a number of reports on the gas-sensing properties of GaN Schottky diodes [3], but no comparisons of how different metals perform and little information in the temperature dependence of the time response. In this paper, we present the characteristics of Al/GaN Schottky diodes for sensing dilute H_2 concentrations in N_2 ambient at different temperatures. The Al metallization is found to produced large changes in forward current of the diodes due to its higher catalytic cracking efficiency for nitrogen and hydrogen. All samples of diodes are found to provide sensitive detection of nitrogen or hydrogen at temperatures as low as 25°C.

MATERIALS AND METHODS

Starting samples of n-type GaN ($1\text{-}3\times10^{17}$ cm^{-3}, 3-5μm thick) layer grown on Si substrates were used for this study. The GaN was first treated for 10 min in 1:3 HCl: HNO_3, followed by the deposition of Al by thermal evaporator coating Edward 306 at pressure of ($5*10^{-5}$ Torr) through metal- mask projection, producing a large area Al ohmic contact to the GaN. The gas sensing experiments were carried out in a homemade testing chamber using air, N_2 and 2% H_2 in N_2 gases at a normal pressure of 1 atm. and over the temperature range of (25-500°C). The test fixture showed in Figure 1. inserted into the chamber with wires leading from the probes through electrical feedthroughs to a Keithley 237 source-measurement unit for current–voltage (*I–V*) measurements. The time response of samples was measured at different temperatures for gases in this study.

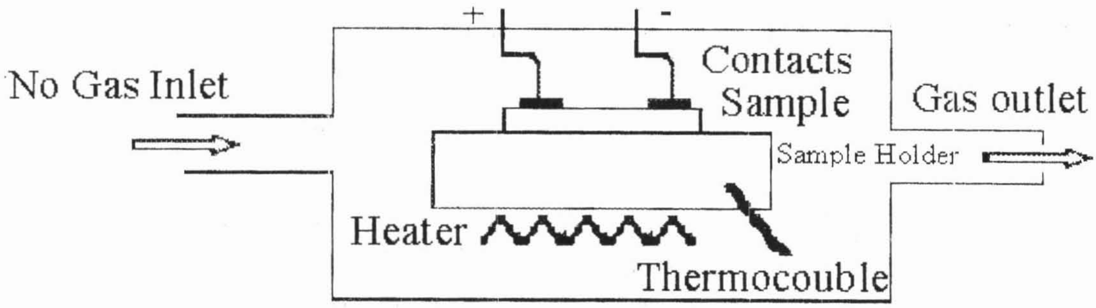

Figure1: Experimental setup for testing the gas sensor.

RESULTS AND DISCUSSIONS

Figure 2 shows the time response of Al/GaN diodes to switching for N_2 and 2% H_2 in N_2, at a measurement temperature 100°C and 200°C with the diode biased at 2 V forward bias. When 2% hydrogen introduced, I_f increase dramatically and when the chamber is started with only nitrogen, I_f decreased; both occasion behaves like a switch or time-responsive. This observation may be due to hydrogen as the only species able to diffuse through a dense noble metal layer into deeper lying layers of the semiconductor device. The hydrogen sensitivity is normally explained by the formation a H-induced dipole layer at the interface of the GaN and the oxide layer. As shown in Figure 3 on the right-hand side, molecular hydrogen dissociates at the Al surface, penetrates through the bulk and builds up a dipole layer by chemisorptions at the interface. The dipole moment is oriented out of the GaN leading to a negative voltage drop [4]. The potential drop at the interface is balanced by a modulation of the surface state occupation and for a low surface state concentration also by a modulation of the depletion layer in the semiconductor. The barrier height Φ_B is given by ($\Phi_B = \Phi_m - \chi_s$), where Φ_m is the metal work function, χ_s the electron affinity of GaN. From the forward I–V characteristics, we were able to measure $\Delta\Phi_B$ of 937 meV at 25°C and 778 meV at 300°C for Al/GaN diodes upon exposure to the N_2 whereas $\Delta\Phi_B$ of 928 meV at 25°C and 586 meV at 300°C for 2% H_2 in N_2 ambient. The lowering of the barrier due to accumulation of hydrogen at the Al/GaN interface is consistent with the formation of the dipole layers at the interface, as suggested previously [4]. Even at this relatively modest temperature, the change in forward current for a fixed bias of 2 V is readily detectable and shows there is sufficient cracking of the H_2 for the diode to be a sensitive gas detector.

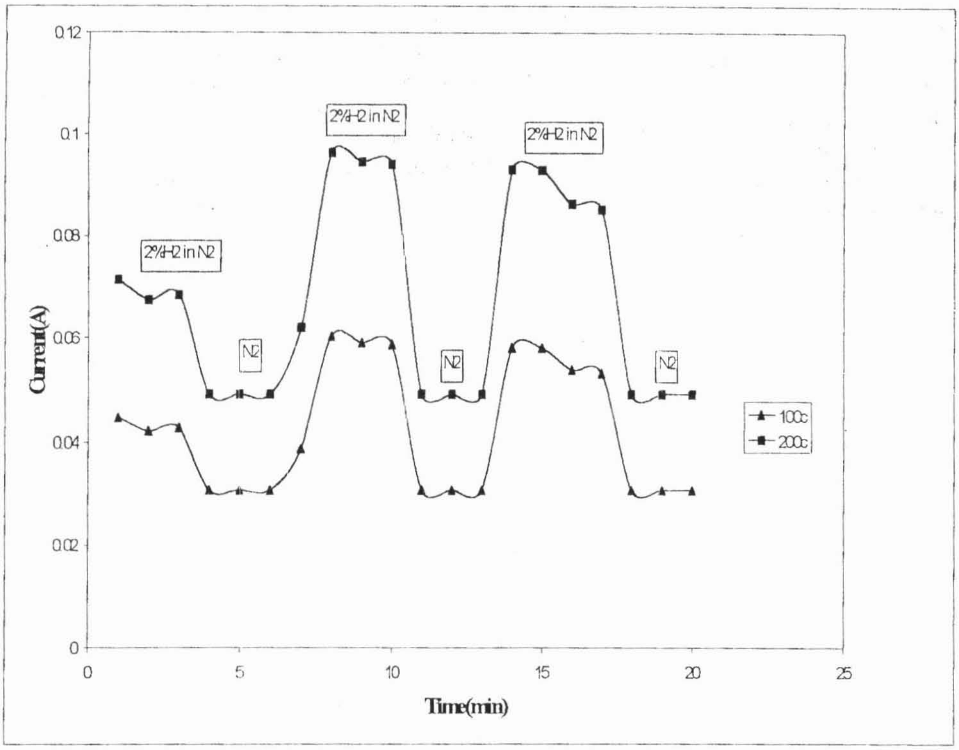

Figure 2: Time response at 100°C and 200°C of forward current of a Al/GaN diode forward biased at 2 V, upon switching for N2 pure ambient and 2% H2 in N2.

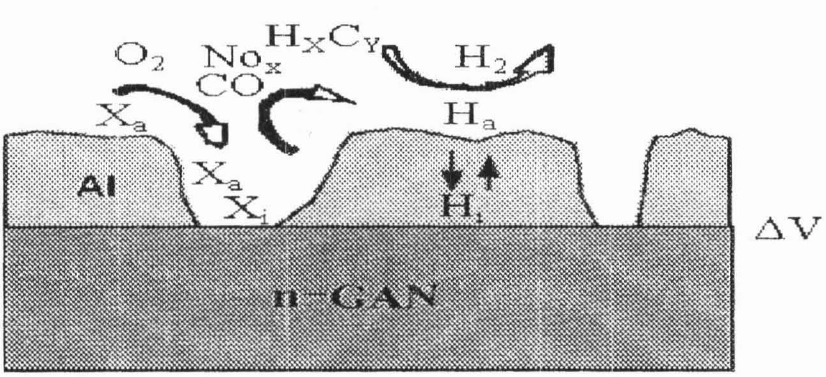

Figure 3: Proposed gas-sensing mechanisms underlying the function of AL /GaN Schottky barrier devices
(Ha, Hi: adsorbed and interfacial Hydrogen; Xa, Xi: adsorbed and interfacial molecules).

The diffusion of hydrogen through the Al layer is not the limiting factor in the time response of the diodes, but rather the mass transport of gas into the enclosure as we have observed by altering the gas introduction rate. Figure 4 shows forward I–V characteristics from Al/GaN diodes for three different gases (N_2, 2% H_2 in N_2 or air) at 25°Cand 300°C. There is a shift of 0.1 V at 25°C and 0.6 V at 300°C in the voltage needed to maintain a forward current of 20 mA. These changes in forward characteristics are easily large enough for the devices to be effective and sensitive gas sensors, as reported previously [5]. The use of either air or gases as the ambient produced significant increases in forward current. Since the H_2, O_2 and F_2 in these gases can affect the dipole layer at the Al/GaN interface because of their reactivity; the electric field under the Al gate is altered and produces the resulting change in diode forward current. The diodes were operated up to 25°C for extended periods without deterioration of the Al contact, although this is a significant concern for higher temperatures due to the possibility of (AlGa or nitride or hydride) formation. For very high operating temperatures, it is desirable to use either a metal–oxide–semiconductor (MOS) approach or else employs more thermally stable metallization. Also Figure 4 shows the forward I–V characteristics from Al/GaN devices in air and N_2 or 2% H_2 in N_2 ambient at both 25 and 300. The change in forward current upon changing the gas became larger at higher temperatures due to the increased dissociation efficiency of the gas molecules. The dissociation can occur through a catalytic reaction with the Al gate, or through additional surface reactions on the semiconductor.

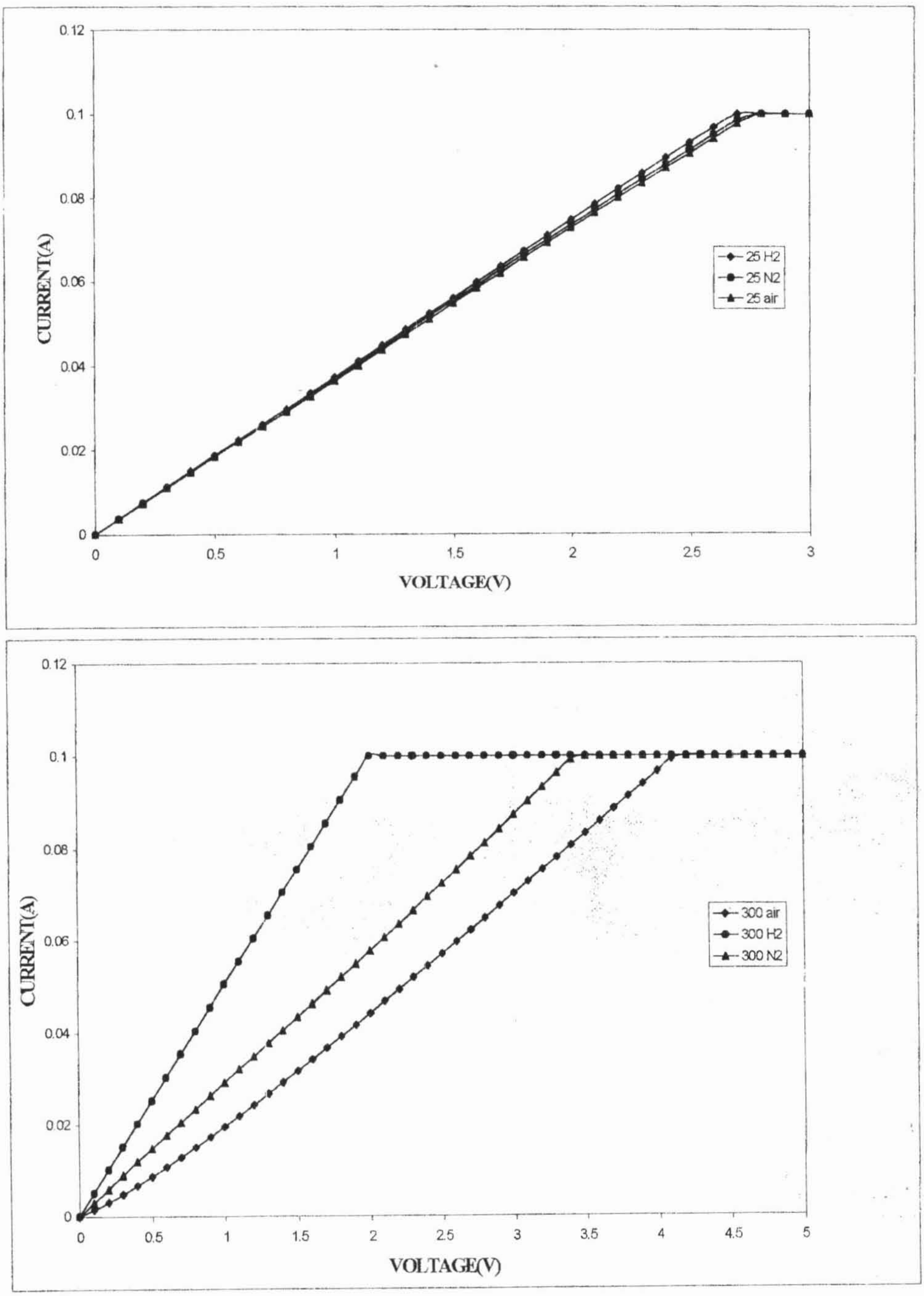

Figure 4: Forward I–V characteristics from Al/GaN diodes measured in air, N2 pure and 2% H2 in N2 ambient at R.T 25°C and 300°C

CONCLUSION

In summary, Al/GaN diode rectifiers of the type used for high power electronic applications are also shown to be effective gas sensors for a range of gases, including H_2 and N_2. The time response of the diodes is limited by the gas mass flow transport characteristics, with the intrinsic response due to changes in the interfacial OH-dipole layer being very rapid, so that the sensors can be used for applications such as space flights or monitoring of manufacturing processes. For very high operating temperatures, it is desirable to use either a metal–oxide–semiconductor (MOS) approach or else employs more thermally stable metallization.

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